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THE PYRITE GEO-THERMOMETER.

F. GORDON SMITH.

ABSTRACT.

A relation between the thermo-electric potential of electronically conducting crystals and the temperature at which they are formed is deduced, certain conditions remaining similar. A device for measuring the thermo-electric potential of pyrite against a metal and the empirical relation of the potential to the temperature of formation is described. Used in combination with two-phase liquid inclusion measurements, the device also serves to measure the hydrostatic pressure at the time the pyrite crystallized.

IN this journal, a notice appeared in 1942 describing a device for determining the temperature at which any given crystal of pyrite crystallized. Since that time, the circuit of the device has been modified, and it has been tested in several ways. No anomalous results have been noticed, and several results which agree with temperature determinations by the liquid inclusion method have been obtained. Therefore the instrument and its calibration will be described in more detail so that its use may become more general.

For a discussion of the relationships between electrical properties and crystal imperfections of pyrite, and the postulated relationship between crystal imperfections and temperature of formation of pyrite and any other mineral, the reader is referred to the previous papers (1, 2, 3). In a general way, the postulated relationships are as follows:

(1) *Crystals of any one mineral species form more perfect crystals when deposited at a high temperature, less perfect crystals at a low temperature, and the degree of perfection varies continuously between any given limits of temperature of deposition.* This has not been proved rigorously, but it is a well known and much used geological generalization. By "less perfect" is meant crystal lattice discontinuities of any type, probably the most important being lineage structure and accidental holes. An implied condition is that the natural solutions from which the crystals precipitate are of similar character and that the mechanism of crystal growth from the solutions is similar. It will be apparent that the degree of perfection will be composition-sensitive to some

degree. The effect of pressure is difficult to assess. However, I cannot see how an increase in the hydrostatic pressure of the precipitating solution would favor either an increase or decrease in the number of crystal lattice discontinuities to any marked degree, other factors being constant. As a first and probably close approximation, the above postulate may be true with relation to minerals deposited in similar ways, such as in quartz-bearing veins. Comparison of minerals deposited by fumarole gases and hydrothermal solutions may not be justified in this connection. Tuttle and Twenhofel (4) have recently shown that under controlled conditions, the degree of perfection of crystals of $Li_2SO_4 \cdot H_2O$ is a function of the temperature of the precipitating solutions.

(2) *Crystals that exhibit electronic conductivity have a lower specific electrical resistance when the crystal is more perfect and a higher specific resistance when the crystal is less perfect.* This relationship is more or less self-evident, because it would be expected that a break in the crystal lattice continuity would prevent the passage of conducting electrons at that place if the direction of the current was at an angle other than parallel to the lattice break. However, this is not the only reason for this relation, as will be seen below.

(3) Combining (1) and (2) above, *crystals of any one electronically conducting mineral species deposited at a high temperature have a lower specific electrical resistance than crystals deposited at a low temperature, and the specific resistance varies continuously between any given limits of temperature of deposition.*

(4) *Crystals which exhibit electronic conductivity have a temperature coefficient of electrical resistance which is more positive when the crystal is more perfect and more negative when the crystal is less perfect,* but whether the range is all on the positive side of zero, all on the negative side of zero, or positive and negative through zero depends upon whether the crystal is near the metallic bond type limit, the homopolar (covalent) bond type limit, or between the two limits, respectively. A picture of the reason for this relationship may be as follows. An ideally perfect crystal between the metallic and homopolar bond type limits is an imperfect electrical conductor due to a smaller density of free or conducting electrons in the crystal structure than in the case of a metal crystal. If the crystal is near the metallic end of the limit, the density of conducting electrons is large, it is a good conductor of electricity, but the temperature coefficient of resistance is positive. The thermal expansion of the crystal structure increases the distance between the constituent atoms, effectively decreasing the chance that the bonding electrons can escape into the conducting level. However, if the crystal is ideally imperfect, most of the free or conducting electrons become trapped by the strongly polarized fields near the lattice breaks, but the number so polarized and trapped decreases as the temperature rises. Thus such a crystal will have a high resistance but a negative temperature coefficient of resistance; as the temperature increases, the resistance decreases. A crystal near the homopolar bond type limit, on the other hand, has a very low conductivity due to very few conducting electrons in the crystal structure, but more can be released from lower energy levels by an increase in temperature. Thus an ideally perfect crystal of this type will have a high resistance and a small negative temperature coefficient of resistance,

and an ideally imperfect crystal will have a very high resistance and a large negative temperature coefficient of resistance. In consequence, a crystal with a bond type between the metallic and homopolar limits, such as pyrite, may have a moderately high resistance and a small positive temperature coefficient of resistance when it is perfect, but a higher resistance and a moderately large negative temperature coefficient of resistance when it is imperfect.

(5) Combining (1) and (4) above, *crystals of any one electronically conducting mineral species deposited at a high temperature have a more positive temperature coefficient of electrical resistance than crystals deposited at a low temperature, and the temperature coefficient varies continuously between any given limits of temperature of deposition.*

(6) *Crystals that exhibit electronic conductivity have a thermo-electric potential which is more negative when the crystal is more perfect and more positive when the crystal is less perfect,* but whether the range is all on the negative side of zero, all on the positive side of zero, or negative and positive through zero depends upon the temperature coefficient of resistance of the ideally perfect crystal. The reason for the change in thermo-electric potential with a change in the perfection of the crystal is not difficult to see. At the hot junction of a crystal and a metal, the metal has *fewer* conducting electrons than it has at the cold junction (a very small positive coefficient). Say the crystal has a large negative coefficient: the density of conducting electrons in the crystal at the hot junction will be *more* than at the cold junction. If the crystal has a positive coefficient, the density of conducting electrons at the hot junction will be *less* than at the cold junction. Furthermore, since the positive and negative temperature coefficients of resistance of poorly conducting crystals are in general very much greater than the small positive coefficients characteristic of metals, it will be apparent that the thermo-electric potentials developed by crystal-crystal couples and even crystal-metal couples will be very much greater than those developed by metal-metal couples.

(7) Combining (1) and (6) above, *crystals of any one electronically conducting mineral species deposited at a high temperature have a more positive thermo-electric potential than crystals deposited at a low temperature, and the thermo-electric potential varies continuously between any given limits of temperature of deposition.*

Relation (7) above is the one upon which the pyrite geo-thermometer is based. The other relations depend upon a measurement of the specific resistance, which is a difficult operation, especially in the case of brittle crystals such as the opaque minerals. It will be apparent that the thermo-electric potential of a crystal is independent of the resistance within the crystal. It is also independent of the contact resistance of the electrodes of the dissimilar conductor on the crystal, and on the spacing between such electrodes.

The arrangement for setting up the thermo-electric potential and relating it to temperature of formation of minerals consists of:

(1) a crystal which conducts electronically,

(2) two metallic electrodes, one hotter than the other, and which can be touched simultaneously to the crystal,

(3) a potentiometer to measure the potential difference between the hot and cold electrode, and

(4) an empirically derived relation between thermo-electric potential and the temperature of deposition of the crystal.

Of all of the electronically conducting minerals (the opaque minerals), pyrite (FeS_2) is the most useful. The specific electrical resistance of pyrite is between approximately 0.002 and 200 ohms per centimeter cube (2, 5), the lower limit presumably being close to that for an ideally perfect crystal. Therefore the resistance is low enough for the thermo-electric effects to set up currents of sufficient strength so that the potential can be readily measured. Also, pyrite is ubiquitous in its occurrence, being present in mineral deposits believed to have been formed at high temperatures and also in others believed to have been formed at low temperatures. It is also present as well formed crystals in most deposits and can be crystallized in the laboratory. Accordingly, the mineral chosen for relating thermo-electric potential and temperature of formation was pyrite.

The electrodes may be of any metal, but stainless steel was finally chosen because of its ease of fabrication, strength, and chemical inertness. They are made in the form of two thin points on $\frac{1}{8}$ inch rods, one of which is heated by means of a small nichrome resistance wire heater. The points are bent toward each other, leaving a space of $\frac{1}{16}$ inch between them. In designing the electrodes, it was found to be difficult to prevent the cooler of the two from rising above room temperature. However, the final calibration includes all such unmeasurable but nearly constant effects. The temperature difference between the electrodes is made nearly constant, and the heat capacity of both electrodes is large. The electrodes are connected to copper wires which lead to the potentiometer circuit. The electrodes are at nearly the same temperature and near room temperature at the places where the copper wires are connected. Another design which has proved useful is an adaptation of a very small soldering iron, the hot electrode being inserted in the hot copper tip. Thermo-electrical effects at the various metal-metal joins are cancelled out in the final calibration.

The potentiometer need not be very elaborate, since the potentials developed are so large that extreme accuracy is not necessary. The most important part of the instrument is the galvanometer, which in some of the circuits designed for this work serves also as a voltmeter for standardizing the instrumental source of voltage. Two simple circuits which have been used are shown in Fig. 1. A photograph of the complete instrument in use is shown in Fig. 2.

The calibration of the thermo-electric potential against the temperature of formation of pyrite is the most critical part of the instrument. It was carried out by selecting crystals of pyrite which are known to have been formed at certain temperatures. Pyrite encrusts brown sphalerite in the low temperature lead-zinc deposits of the Joplin district, Missouri. Newhouse (6) determined the temperature of formation of the brown sphalerite in the ore by the study of liquid inclusions in the sphalerite, the effect of pressure at the time of forma-

tion being considered to be negligible. His results indicated a temperature of formation of 125°–135° C. Since the pyrite was deposited later than the sphalerite (in the specimens at hand), the temperature of the solutions at the time the pyrite was deposited would likely be the same or slightly lower, say

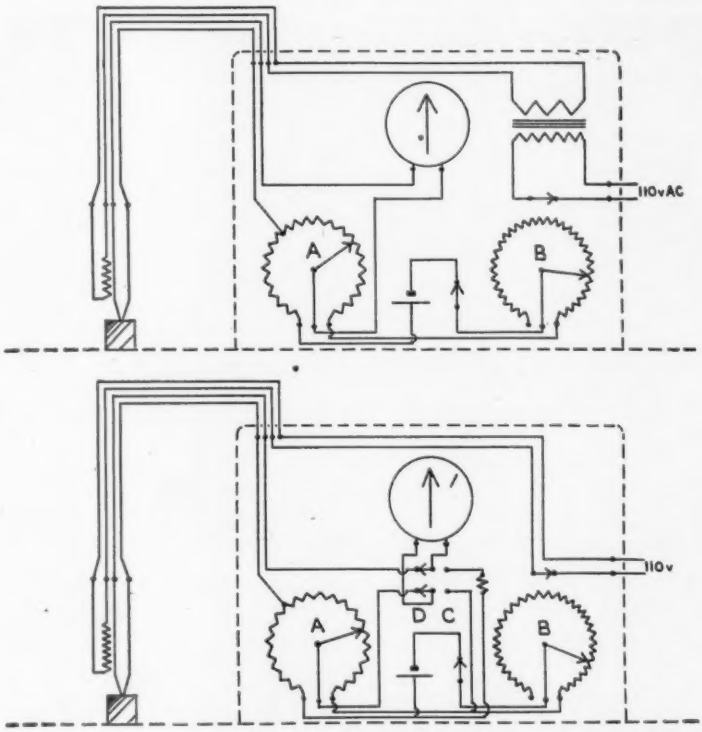

FIG. 1. Two circuits for pyrite geothermometer.

Circuit 1 (upper). Variable resistance A is set at 125° C mark, variable resistance B is adjusted until no deflection of galvanometer when electrodes touch a crystal of Joplin pyrite. Then B is kept constant, A is varied until no deflection of galvanometer when electrodes touch other pyrite crystals. Circuit 2 (lower). Switch is set at C position, variable resistance B is adjusted until galvanometer is deflected to prepared mark. Then switch is set at D position, A is varied until there is no deflection of galvanometer when electrodes touch any pyrite crystal.

125° C. A specimen of pyrite from Joplin with the above relations to sphalerite was polished, and an area was chosen free from other minerals, such as marcasite. The position of the final balance rheostat of the potentiometer (when the thermo-electric potential developed as the electrodes were touched

to the polished surface was balanced by the instrument) was marked 125° C. This point indicated that a very large and positive thermo-electric potential had been set up. Some octahedral pyrite crystals formed at approximately 600° C. in alkali polysulphide melts, with crystal edges about 1 mm long, were tested.

FIG. 2. The pyrite geo-thermometer in use.

The point of balance was marked 600° C., and the balancing potential was such that the thermo-electric potential was very large and negative. As a first approximation, the dial was divided proportionately, each 100° C. representing equal differences of potential. However, concretionary nodules of pyrite gave a reading lower than 0° C. on this basis, and a pyritohedral specimen from Elba, which had crystallized with specular hematite (Fe_2O_3), gave a reading

of about 550° C. This seemed to be too high, if the most likely temperature for specularite to form in the presence of CO_2 and CO is 490° C. (7). When the divisions were altered such that the difference of potential for every 100° C. drop in temperature was made less in the high-temperature range and more in the low-temperature range, then the above Elba pyrite crystal read 490° C., and the concretion, a little above 0° C. Other control points not being known to me, the dial is being used as modified. Possibly more exact data will appear and will be incorporated later. At present the zero potential point is at 395° C. That is, pyrite which has a positive thermo-electric potential against stainless steel is taken to have crystallized at a temperature lower than 395° C., and if it has a negative potential, it crystallized at a temperature higher than 395° C. The actual potentials are functions of the temperature difference of the electrodes and other variables, but the dial used at present is such that the negative potential at 700° C. represents a potential equal in magnitude to the positive potential at 150° C. The accuracy of the readings is probably $\pm 20°$ C. in the low temperature range and $\pm 60°$ C. in the high temperature range. Approximately 300 specimens of pyrite have been tested with the device in the last 5 years, and all of the readings fall between 0° C. and 700° C. on the revised scale.

The electrodes may be touched to crystal faces of pyrite, the interior of broken crystals, polished interiors of crystals, broken crystals in aggregates which are in electrical contact, and to similar groups in polished sections. Broken, polished, and etched surfaces of crystals give very similar readings. Crystal faces, especially those on pyrite in vugs and open veins, often give appreciably lower temperature readings than the interior. Many crystals, such as the above mentioned one from Elba, show no difference between the crystal faces and the interior of the crystal. Since the hot electrode loses heat to the pyrite crystal, the thermo-electric potential falls somewhat if the electrode is held to the specimen. The usual technique is to touch the electrodes to the crystal and observe the direction of deflection of the galvanometer needle. The electrodes are raised, the balance control is moved in the appropriate direction and the electrodes are touched again. Finally a point will be reached where the needle moves slightly one way and then the other as the electrodes are touched to various places on the crystal. This then is taken as the final reading. Of course, many crystals of pyrite of one generation are tested at the same time and the result is averaged. Usually limits of $\pm 50°$ enclose all of the readings, and $\pm 20°$ enclose most of the readings. Great care must be taken that neither electrode is touching a small veinlet or bleb of another conducting mineral, such as chalcopyrite or pyrrhotite. In that event, large anomalous readings are obtained. In several cases, small veinlets of other minerals have been detected by noticing such discordant readings and were subsequently confirmed by the examination of polished sections under the microscope.

It is somewhat difficult to devise a rigorous test of the device, especially in the high temperature part of the range. However, a large number of readings have been taken without any result being proved to be substantially in error. Pyrite from some of the gold-quartz veins of northeastern Ontario and western

Quebec, where the pyrite appears to have been deposited about the same time as albite, scheelite, rutile and quartz, gives a reading of 600° C. Pyrite in quartz veinlets in quartz porphyry in the same region gives readings of 490° to 550° C. Pyrite in quartz-tourmaline veins in the same district gives readings near 550° C. Pyrite from the massive sulphide ore bodies near Sudbury gives readings near 700° C. Several generations of pyrite in one vein can readily be detected, and in all such complex ores, the temperature of formation of the latter pyrite has been found to be lower than that of the earlier pyrite. Crystals of pyrite disseminated in the altered walls of veins usually give a much higher temperature reading than pyrite within the veins.

As an example of one test in the low temperature range, an excellent group of minerals from a vug in the 19th level of the El Potosi mine (Santa Eulalia, Chihuahua, Mexico), was examined. The paragenesis was evident from superposition of crystals, and was seen to be: quartz, dolomite calcite, pyrite (last). The pyrite gave a reading of 100° C. (25° C. lower than the Joplin pyrite). The liquid inclusions were examined by the decrepitation method, which has been used in this department for several months and which will be more fully described later. In essence it is similar to the method used by Newhouse, but consists of heating the mineral until the liquid inclusions explode. The lowest temperature at which the liquid inclusions are one phase is then a few degrees lower than the temperature at which they begin to expode. The effect of the hydrostatic pressure on the solutions at the time the mineral formed can be calculated from the known phase relations of water (8). Making such corrections and assuming that the solutions have the thermal expansion properties of pure water, the temperature of formation of the above minerals was as follows:

(1) quartz—285° ± 10° C.,
(2) dolomite—not determined,
(3) calcite—225° ± 10°C., and
(4) pyrite—95° ± 10° C.

That is, the instrument reading gave 100° ± 20° C., and the liquid inclusion data gave 95° ± 10° C. for the temperature of formation of the pyrite.

It will be realized that the use of two-phase liquid inclusions in geological thermometry is of sufficient exactness only if the hydrostatic pressure on the hydrothermal solutions is known within narrow limits. The lowest temperature at which the inclusions are one liquid phase is the minimum possible temperature of deposition, and the minimum possible pressure is the corresponding vapor pressure of the solution at that temperature. The maximum possible temperature and pressure are given by the intersection of the $t - p$ curve for the specific volume of the inclusion (in the one phase condition) and the mean $t - p$ curve for the earth. There is no upper limit in the case of liquid inclusions with a large gas bubble, since the slope of the $t - p$ curve for large specific volume diverges from that of the mean $t - p$ curve for the earth. Liquid inclusion data will allow a calculation of the temperature of deposition of minerals if the pressure during deposition is known. Conversely, if the temperature of deposition is known, the pressure may be calculated.

As an example of a determination of the pressure of deposition, using liquid inclusions and thermo-electric potential of pyrite, the following calculations were made on pyrite from the 700-foot level of the Bevcourt Mine, Louvicourt Township, Quebec. The decrepitation temperature was found to be 395° C. If the necessary pressure for the liquid inclusion to break out is taken to be 500 atmospheres, the one-phase temperature would be 340° C. The pyrite geothermometer gave a reading of 550° C. Assuming that the liquid inclusions have the thermal expansion properties of pure water, the liquid had a specific volume of 1.7 at the one-phase condition. At a temperature of $550° \pm 60°$ C., the pressure would have to be 2700 ± 1700 bars or 6.6 ± 1.8 miles deep in the earth in order to keep the liquid at that density. Therefore the deposition took place when the surface was 6.5 ± 1.8 miles above the present surface. This indicates that the mineralization probably was pre-Palaeozoic, since nearly flat-lying Ordovician rocks are present less than 100 miles to the southwest. It probably was also pre-Huronian, because nearly flat-lying Huronian rocks are present 50 miles to the southwest. Therefore the veins were probably formed during or soon after a pre-Huronian orogeny, possibly the Algoman.

Minerals other than pyrite could be tested for thermo-electric potential variations as a function of temperature of deposition. However, few opaque minerals are free from major solid solution effects, and few occur over such a wide temperature range as pyrite. Sphalerite has too high a resistance to be used. Pyrrhotite and magnetite vary in composition within wide limits, and presumably this would alter their electrical properties. Galena might be suitable, and it has been noticed that galena crystals from various localities have thermo-electric potentials in a wide range.

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TORONTO, CANADA,
May 20, 1947.

REFERENCES.

1. Smith, F. G.: Variation in the electrical conductivity of pyrite. Toronto Univ. Studies, Geol. Ser., 44: 83–93, 1940.
2. ——: Variation in the properties of pyrite. Am. Mineralogist, 27: 1–19, 1942.
3. ——: Lineage structure and conditions of deposition of pyrite. ECON. GEOL., 37: 519–523, 1942.
4. Tuttle, O. F., and Twenhofel, W. S.: Effect of temperature on lineage structure in some synthetic crystals. Am. Mineralogist, 31: 569–573, 1946.
5. Slichter, L. B., and Telkes, M.: Electrical properties of rocks and minerals. Handbook of physical constants. Geol. Soc. America Spec. Paper 36: 310, 1942.
6. Newhouse, W. H.: The temperature of formation of the Mississippi valley lead-zinc deposits. ECON. GEOL., 28: 744–750, 1933.
7. Butler, B. S.: A suggested explanation of the high ferric oxide content of limestone contact zones. ECON. GEOL., 18: 398–404, 1923.
8. Goranson, R. W.: Temperature-pressure-volume and phase relations of water. Handbook of physical constants. Geol. Soc. America Spec. Paper 36: 203–212, 1942.

REPORT OF THE COMMITTEE ON RESEARCH ON ORE DEPOSITS OF THE SOCIETY OF ECONOMIC GEOLOGISTS.[1]

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INTRODUCTION.

On February 4 and on April 25, 1946, small groups of geologists met in New York, at the invitation of C. H. Behre, Jr., to discuss informally the development of a program of research in ore deposits. From those meetings, from discussions with other mining geologists and from a considerable correspondence with yet others, the Committee has chosen a tentative and experimental procedure which might be briefly characterized as "research in the field of research on ore deposits." The essence of the proposed technique is to solicit suggestions and to publish them periodically.

It is the Committee's immediate plan to present, from time to time, collections of concisely defined subjects which, in the opinion of the Committee or its Consultants, are in need of further study. Whenever possible, these subjects will be defined by the geologist most familiar with the subject and the definitions shall, when feasible, summarize (*a*) the present state of our knowledge, (*b*) who is now working on what phases of it, and (*c*) what other phases should be studied.

It is obvious that a technique of definition and summary must be worked out and that the best approach to such a technique will be an experimental one.

The Committee regards any research as being composed of three elements; (*a*) the subject, (*b*) the man, and (*c*) the facility, which includes such items

[1] This is the second of a series of Reports of the subcommittees on Research of the Society of Economic Geologists, both of which were preceded by the Report of the "General Committee on Research of the Society of Economic Geologists," by Charles H. Behre, Jr., Chairman.

as salary, laboratory, and working funds. For the time, the Committee chooses to concern itself principally with the subject, believing that the subject will attract the man who can later be provided with the facilities. As most of the present generation of geologists engaged primarily in the field of ore deposits are occupied with their own problems, we base our main hope of effectively stimulating research in bringing suitable subjects to the attention of the present and future graduate students and, more generally, to the attention of all persons now beginning their careers who are looking over the field of ore deposits in search for subjects to their liking.

A review of the work of past committees in this field gives some guide to future procedure:

COMMITTEES OF THE NATIONAL RESEARCH COUNCIL.

At the invitation of the Division of Geology and Geography of the National Research Council, a Committee on Processes of Ore Deposition was organized in the spring of 1927, under the Chairmanship of Waldemar Lindgren. This Committee continued under the Chairmanship of Bastin, Newhouse and Lovering until 1942, when, because of the impracticability of working under war conditions, it was discontinued. Annual reports of this Committee were mimeographed and included as Appendices in the Annual Report of the Division of Geology and Geography of the National Research Council, as summarized in Table I.

TABLE I.

REPORTS ON ORE DEPOSITS OF THE DIVISION OF GEOLOGY AND GEOGRAPHY OF THE NATIONAL RESEARCH COUNCIL.

(Letters in parenthesis indicate the Appendix to the annual Division report.)

Year	Committee	Chairman	Sub-Committee	Chairman	Report
1928	Processes of Ore Deposition	Lindgren (G)			
1929	do	do (M)	Criteria of Paragenesis of Minerals	Bastin (R)	
1930	do	do (K)	do	do (L)	
1931	do	do (K)	do	do (L)	[1]
1932	do	Bastin (M)			
1933	do	do (J)			
1934	do	do (J)			
1935	do	Newhouse (L)	Mississippi Valley Mineralization	Bastin (L)	
1936	do	do (M)	do	do (M)	
1937	do	do (H)	do	do (H)	
1938	do	do (I)	do	do (I)	[2]
1939	do	do (F)			
1940	do	do (A)			[3]
1941	Problems of Ore Deposits	Lovering (J)			
1942	do	do (M)			

[1] Bastin, E. S., Graton, L. C., Lindgren, W., Newhouse, W. H., Schwartz, G. M., and Short, M. N.: Criteria of age relations of minerals, ECON. GEOL. 26: 561–610, 1931.

[2] Bastin, E. S. and others: Contributions to a knowledge of the lead and zinc deposits of the Mississippi Valley Region, Geological Society of America, Special Paper 24, 156 pp., 1939.

[3] Newhouse, W. H. and others: Ore Deposits as Related to Structural Features, Princeton University Press, 280 pp., 1942.

Some of these reports contain thoughtful suggestions about needed research. Of these suggested subjects, some have been investigated and the results published, others are now in process of investigation, and still others

are as yet suggestions. Outstanding among the products of this committee are the three publications indicated in the footnote to Table I.

Because the Annual Report of the Division of Geology and Geography of the National Research Council may not readily be available to all geologists, it has seemed worth while to list some of the subjects suggested by these earlier committees.

1928 (14 pp.).

This thoughtful report has the following outline:

1. General problems as to assumptions and definitions.
2. Distribution and relations to accompanying rocks.
3. Structural features of ore deposits.
4. Mineralogical and chemical features of ores.
5. Physico-chemical investigations.
   - A. Movement of solutions through rocks.
     1. Rocks not attacked by the solution.
     2. Rocks chemically attacked by the solution.
   - B. Problems in colloidal chemistry.
     1. Precipitation of colloidal oxides.
     2. Precipitation of metallic sulphides.
     3. Precipitation of other salts.
   - C. Separation of chlorides by sublimation.
   - D. The system silica-water-calcium carbonate.
   - E. Problems in solubility.
   - F. Problems regarding gangue minerals.
   - G. Sulphide melts.
   - H. Magnetite and specularite.
   - I. Unmixing.
   - J. Post hypogene and pre-supergene changes in ores.
   - K. A study of pseudomorphs.
   - L. Problems of differentiation of metallic substances in magmas.

1929 (2 pp.).

Announces the formation of the *Sub-Committee on Criteria of Paragenesis of Ore Minerals.*

1930 (4 pp.).

Gives table of contents for report on "Criteria of age relations of minerals."

1931 (2 pp.).

Announces completion of report on "Criteria of age relations of minerals."

1932 (2 pp.).

Eleven subjects briefly suggested.

1933 (6 pp.).

Announces organization of *Sub-Committee on Mississippi Valley Mineralization.* Lists research projects under way.

1934 (18 pp.).

Abstracts data on mineralization in Mississippi Valley.

1935 (10 pp.).

Gives outline for report on "Mississippi Valley mineralization" and abstracts current papers in that field. Announces formation of a Sub-Committee to obtain physical and chemical data that have an important bearing on ore deposits.

1936 (4 pp.).

Anounces three new projects: (1) Investigation of the system CO_2–H_2O under varying pressures in equilibrium with a silicate melt at a constant temperature of 1,000°; (2) Investigation of fracturing in dolomite and limestone; and (3) Influence of structure on ore deposition.

1937 (2 pp.).

Reports progress on "Mississippi Valley mineralization" and a start on "Ore deposits as related to structural features."

1938 (2 pp.).

Announces completion of "Mississippi Valley mineralization" and receipt of about 70 manuscripts for "Ore deposits as related to structural features."

1939 (1 p.).

Announces approximate completion of "Ore deposits as related to structural features."

1940 (1 p.).

Announces completion of "Ore deposits as related to structural features."

1941 (10 pp.).

This excellent report briefly defines the following suggested problems:

1. The condition and behavior of the metallic elements in the magma.
2. Magmatic segregations and the anhydrous sulphide systems.
3. The departure of ore constituents from the magma.
4. The transportation of metals in hydrothermal solutions.
5. Replacement.
6. Criteria for interpretation of geologic conditions.
7. Colloidal chemistry.

It summarizes, in the outline form given below, the various geochemical problems that the committee has discussed.

Summary of Problems Suggested.

October 24, 1940.

A. Trace elements through crystallization of magmas.
    1. Study of natural rocks and minerals.
        A. Spectroscopic tests for metals.
        B. Spot tests.
    2. "Tracer" elements in artificial magmas.

B. How do elements leave the magma?

1. Order in which the volatile constituents leave the magma.
   A. Long-range field and laboratory study.
2. Solubility studies at high temperatures.
   A. Extension of SiO_2-H_2O studies to include metals.
      (1) MoO_3-H_2O (soluble oxides).
      (2) MoO_3-SiO_2-H_2O.
   B. Solubility of carbonates at high temperatures.
   C. Anhydrous systems.
      (1) Sulphide systems.
         a. Binary.
         b. Ternary.
      (2) Silicate-sulphide systems (magmatic segregation).
         a. Olivine-nickel-sulphur.
            a. Condition of sulphur in melt.
            b. Partition of Ni between silicate and sulphide.
   D. Systems with water.
      (1) H-O-S.
      (2) Iron oxide—water.
      (3) One sulphide and water.
         a. FeS-S-H_2O.
         b. Copper sulphide—water.
         c. Barium sulphide—water.
      (4) Lead chloride—water.
      (5) Zinc-chloride—water.
      (6) In general: solubilities of Al, Zn, Cu, Fe, Pb to be determined in solutions of SO_4, Cl, CO_3, HCO_3, F, S at temperatures of 100° to 250°. For example: the systems Al_2O_3-SO_3-H_2O; K_2O-Al_2O_3-SO_3-H_2O; ZnO-CO_2-H_2O; etc. (arranged in order of increasing experimental difficulty).
      (7) Summarize and evaluate work done.
3. Nature of the ore-carrying solutions to be interpreted from field evidence, replacement and rock alteration studies.
   A. Content: mostly chlorides, sulphates, carbonates or bicarbonates and sulphides.
   B. Concentrations: relatively dilute for experimental work at start unless other researches suggest different conditions.
   C. Temperature range: 100° to 550°.
   D. Replacement.
      (1) Apparatus.
         a. Material for bombs to stand T. and P. and solutions used.
         b. Reaction chamber to which solutions can be supplied continuously under high pressure.
      (2) Replacement of carbonates by ore minerals.
      (3) Replacement of one ore mineral by another.
      (4) Selective replacement.
   E. Wall rock alteration: same technique as for replacement.
      (1) Alteration of feldspar to sericite under wide variety of conditions.
      (2) Alteration of feldspar to clay and kaolin-like materials.
      (3) Effect of different types of solution on
         a. granite.
         b. diabase.

C. Alkalinity-acidity.
1. Theoretical and experimental work on pH at high temperatures, above 300° C.
2. "Diagnostic minerals" (pH of formation).
   A. Summary of the literature.
   B. Experimental work.
      (1) Vary composition of mixture (Esp. SiO_2: alk. ratio).
      (2) Effect of temperature.
3. Crystal habit of a given mineral.
   A. Summary of the literature.
   B. Experimental work.
      (1) With organic compounds (for preliminary work if they prove easier to manipulate than inorganic crystals).
         a. Use different solvents.
         b. Effect of complex solutions.
         c. Effect of temperature.
      (2) With soluble inorganic salts.
         a. Effect of pH.
         b. Complex solutions.
         c. Effect of temperature.
      (3) With minerals.
         a. Effect of pH or SiO_2: alk. ratio.
         b. Effect of temperature.

D. Colloids.
1. Temperatures at which various colloids may exist in solution (*i.e.*, above which they cannot exist—experimental attack).
2. Temperatures at which various materials may come down as colloidal precipitates.
   A. From colloidal solutions.
   B. From true solutions.
3. Effect of motion through materials of various pore sizes.
4. Criteria for interpretation of colloform structures.
   A. Do colloidal gels crystallize to produce such forms? Valid criteria for true colloidal genesis; checked by experiment, *e.g.*, shrinkage cracks, radiate-acicular spheroids.
   B. Rates of crystallization at various temperatures and pressures. pH and ionization of hydrous silicate solutions ("silicic acids") at higher temperatures.

1942 (1 p.).

Since many members are engaged in war work, recommends that the Committee be discontinued.

Bastin's report "Suggestions concerning desirable lines of research in the fields of geology and geography," published by the National Research Council in 1936, has a section on metalliferous deposits (pp. 32–38) of some general interest. Suggested subjects are:

1. Correlation of metalliferous deposits with igneous bodies.
2. Study of channelways.
3. Rock alteration associated with ore deposits.
4. Effect of mechanical and chemical characteristics of wall rocks on the structure and contents of veins and replacement bodies.
5. What becomes of ore-depositing solutions after they have accomplished their mineralization.

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6. Re-opening or recurrent mineralization.
7. Iron-depositing bacteria.
8. Origin of glauconite.
9. Bauxitization and lateritization.

Lovering's "Report of the Interdivisional Committee on borderland fields between geology, physics, and chemistry," published by the National Research Council in 1937, is a stimulating scrutiny of fields that are fundamental to the subject of ore deposition. A list of the major headings in this report, with the number of pages devoted to each, follows:

Fundamental constants of geologic materials (7 pp.).
Deformation and rupture of geologic materials (8 pp.).
Elasticity, gravity, electricity and magnetism (11 pp.).
Hydrodynamics (6 pp.).
Heat (3 pp.).
Radioactivity (2 pp.).
Thermodynamics of geochemical processes (10 pp.).
Chemical effects of differential pressure (1 p.).
Magmatic emanations (3 pp.).
Colloids (4 pp.).
Metasomatic replacement (3 pp.).
Simplification of rock analyses (4 pp.).
Analytical investigations of rocks and minerals (1 p.).

Among the tangible consequences of this report might be mentioned the "Handbook of physical constants" edited by Birch, Schairer and Spicer and published as Special Paper 39 by the Geological Society of America in 1942; and "Theory of scale models as applied to the study of geologic structures" by M. K. Hubbert, and published in vol. 48 of the Bulletin of the Geological Society of America in 1938. The intangible consequences of the report in stimulating thought in the borderline fields cannot be measured.

A new National Research Council committee, organized in 1947 under the Chairmanship of J. F. Schairer, will begin studies in the borderland between geology and physics and chemistry, fields of primary interest to students of ore deposits.

A symposium on Applied Sedimentation is being sponsored by the National Research Council, under the Chairmanship of Parker D. Trask. The primary purpose is to acquaint geologists and engineers with possible uses of sedimentation in their work. In mining geology, topics that have been suggested include: Sedimentary mineral deposits, selective mineralization of sedimentary rocks, processes of precipitation in bodies of water, lateritization, and geochemical studies of soils. Dr. Trask would welcome suggestions from mining geologists as to topics that might be considered.

THE SELECTION OF SUBJECTS FOR RESEARCH.

From the discussions held in New York on February 4 and April 25, 1946, and from correspondence during that period, a list of 30 subjects meriting serious consideration for further research was compiled.

Between November 30, 1946 and January 15, 1947 this list was sent to

thirty geologists, including all those who had taken part in the discussions in New York, whose primary interest is in the field of ore deposits. The geologists were asked to assign to these suggested subjects an order of preference, number 1 being the highest preference and number 30 the lowest. It was hoped that this preferential numbering would indicate what subjects each geologist believes to hold most promise for furthering our knowledge of ore deposits.

In response to the thirty questionnaires sent out, twenty-four replies were received, of which twenty had been answered in sufficient detail to give some basis for tabulation. Five geologists submitted a total of eight additional subjects, which were included in some of the questionnaires that were sent out in January. Most of the questionnaires were returned without comment, but two were accompanied by letters approving the Committee's approach to the problem and one was strongly critical of that approach, pointing out that it savored of "directed research."

The twenty replies that had been made in some detail are summarized in Table II. Subjects are arranged vertically and the horizontal headings "a" to "t" represent individual geologists. It is apparent that there is a wide variation in the individual judgments as to which of the suggested subjects are the most important.

In order to arrive at a collective judgment of the relative urgency of the thirty subjects originally submitted, the individual judgments were weighted in the following manner: Subjects given number one (the highest priority) were weighted as 30 points and subjects given number 30 (the lowest priority) were weighted as one point. Intermediate priorities received corresponding weightings according to the formula, 31 minus the priority number equals the weighting number. The sum of the individual weighting numbers is given in the second column at the left of the table under the heading "weights" and the *collective priority* representing the combined judgment of the twenty geologists responding is given in the first column on the left under the heading "Order."

With full realization of the pitfalls of such a pseudo-statistical treatment of data which may, in some cases, be hurried snap judgments, the procedure outlined above has seemed to be the most objective approach to the combined judgments of twenty geologists familiar with the field of ore deposits. Admittedly more geologists should be consulted, for a base of only twenty is too narrow.

Listed below are the subjects which have emerged in the first ten places of collective prior preference:

1. Development of "sericite-kaolin" type alteration as a guide to ore.
2. Cause for selective localization on certain limestone beds.
3. Volcanic emanations as keys to ore transport.
4. Comparison between "productive" and "barren" igneous rocks.
5. Geochemistry and localization of dolomitization.
6. Detailed studies of zoning in ore districts.
7. Expansion of geophysical methods applicable to ores, especially self-potential, seismic, electronics.

TABLE II.

SUMMARY OF THE RETURNS FROM THE QUESTIONNAIRE OF NOVEMBER 30, 1946.

	Subject	Combined judgment Order	Combined judgment Weights	Individual judgments of the relative importance of the subjects suggested (Each letter represents a geologist who replied to the questionnaire) a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
Areal:	Accurate mapping, Great Basin	9	237	26	—	25	2	—	1	32	6	1	—	10	—	24	7	—	—	—	1	—	2
	Accurate mapping, Nevada	19	131	28	—	26	—	—	—	31	—	2	—	—	—	22	6	—	—	1	1	—	—
	Accurate mapping, North Idaho	27	62	30	—	27	—	—	—	30	—	4	—	—	—	25	8	—	—	—	—	—	—
	Regional bulletins on foreign deposits	21	102	17	—	28	—	—	—	29	—	—	—	—	3	23	—	12	3	—	—	—	—
Igneous rocks:	Emplacement of igneous rocks in relation to favorable ore structures	9	237	14	5	10	—	7	—	9	—	—	—	6	14	11	22	—	4	—	—	2	—
	Comparison between "productive" and "barren" igneous rocks	4	307	23	3	9	—	6	6	24	1	—	7	8	4	16	6	5	—	—	—	—	6
	Experimental studies of magmatic segregation	29	57	24	—	—	—	—	—	23	—	—	—	—	—	8	12	—	—	—	—	—	—
Zoning, etc.:	Causes for downward limits of hypogene deposits	8	256	15	2	8	—	5	—	1	—	11	—	—	—	5	23	6	5	—	—	4	—
	Detailed studies of zoning in ore districts	6	267	27	—	11	—	—	2	2	7	5	5	—	12	12	18	—	—	—	5	—	3
	Fundamental study: genesis of contact metamorphic deposits	23	94	12	—	—	—	—	—	10	—	—	—	4	—	26	—	9	—	—	—	—	—
Ore transport:	Volcanic emanations as keys to ore transport	3	312	11	—	1	1	—	5	3	—	13	—	—	13	4	25	3	6	—	—	5	1
	Colloidal transport of ores	22	101	1	—	24	—	—	—	14	—	12	—	—	—	28	—	7	—	—	—	—	—
	Transport and deposition of SiO_2	10	231	22	—	2	—	—	12	11	—	—	—	—	2	13	1	8	—	—	4	—	4
	Transport and deposition of gold	18	149	13	—	2	—	—	—	13	—	9	—	—	—	14	13	—	—	—	—	—	4
	System Fe-S-pyrite (geochemistry)	13	192	3	—	3	—	—	13	12	—	—	—	—	11	15	2	—	—	—	—	—	5
Rock alteration:	Geochemistry and localization of dolomitization	5	280	4	—	7	—	2	—	15	4	—	—	—	—	2	14	2	2.	2	—	—	8
	Development of "sericite-kaolin" type alteration as ore guide	1	410	16	1	6	3	—	4	4	3	14	2	9	7	1	4	—	—	3	2	—	7
Types and genesis:	Monographs on specific types (like Bastin's "Miss. Valley" type)	16	170	2	—	12	—	—	3	8	—	3	—	—	—	—	—	—	7	—	—	—	12
	Monograph on pegmatites	24	85	18	—	22	—	—	—	6	—	—	—	—	15	9	—	—	—	—	—	—	—
	Monograph of genesis of porphry copper ores	20	121	10	4	23	—	—	—	7	—	—	—	—	—	27	19	—	—	6	—	—	—

TABLE II.—*Continued.*

	Subject	Combined judgment Order	Combined judgment Weights	Individual judgments of the relative importance of the subjects suggested (Each letter represents a geologist who replied to the questionnaire) a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t
"Structural" localization:	Causes for selective localization on certain limestone beds	2	329	5	—	15	—	1	11	16	5	—	3	—	10	3	17	4	8	4	3	—	—
	Permeability barriers in localization	11	207	8	—	14	—	—	—	25	8	—	—	7	—	10	16	10	—	—	—	6	9
	Experimental load and stress deformation of rock types (including photoelasticity)	12	195	9	—	13	—	—	—	22	9	10	—	2	—	6	3	—	—	—	—	—	10
Geochemistry:	Refinements in trace elements studies (spectroscopy)	15	173	25	—	4	—	—	2	17	—	—	—	—	5	17	24	—	—	7	—	—	3
	Geologic thermometry, expanded applications	14	187	7	—	5	—	—	10	18	—	—	6	—	1	27	5	—	—	—	—	—	13
Weathering:	Tropical lateritic weathering, especially iron and aluminum	15	173	6	—	19	—	—	—	26	—	15	—	—	6	18	21	11	1	—	—	—	14
	Oxidation of base metals	31	55	19	—	20	—	—	—	21	—	—	—	—	—	20	20	—	—	—	—	—	—
	Leached outcrop studies (field and laboratory)	17	165	21	—	16	—	4	8	19	—	—	—	11	8	19	11	—	—	—	—	—	—
Geophysics:	Expansion of geophysical methods applicable to ores, especially self-potential, seismic, electronics	7	264	30	—	21	—	3	9	20	2	—	1	—	9	21	10	1	—	5	—	7	—
Miscellaneous:	The "model" as applied to ore theories (critical evaluation of logic)	32	44	20	—	—	—	—	—	27	—	—	—	—	—	7	26	—	—	—	—	—	—
Subjects suggested later:	Study of low-grade disseminated Cu, Pb, Zn ores with regard to future supplies	28	59	—	—	—	—	—	2	28	—	—	4	—	—	—	—	—	—	—	—	—	—
	Monograph on epithermal precious metals	25	81	—	—	17	—	—	—	5	—	6	—	—	—	—	15	—	—	—	—	—	—
	Integration of detailed time relationships in the system: igneous history—structural dynamics—mineralization	26	63	—	—	18	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	11
	Causes and conditions of ore deposition vs. conditions localizing ore bodies	33	28	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—
	Critical comparison of "vertical" and "lateral" zoning	34	26	—	—	—	—	—	—	—	—	—	—	5	—	—	—	—	—	—	—	—	—
	Influence of host rock or gangue on migration of metals in the oxidized zone	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	Host rock as determinant of texture and mineralogy of an ore deposit	35	24	—	—	—	—	—	—	—	—	—	7	—	—	—	—	—	—	—	—	—	—
	Fracturing or cracking along or in a specific bed or layer as a cause for the localization of ore	36	23	—	—	—	—	—	—	—	—	—	8	—	—	—	—	—	—	—	—	—	—
	Localization of ore deposits within the continental framework	30	56	—	—	—	—	—	7	—	—	—	—	—	—	—	—	—	—	—	—	1	—
	Metallogenetic provinces	32	28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—

8. Causes for downward limits of hypogene deposits.
9a. Accurate mapping, Great Basin.
9b. (tie) Emplacement of igneous rocks in relation to favorable ore structures.
10. Transportation and deposition of SiO_2.

Having arrived at this selection of subjects, the Committee then chose a geologist to prepare a brief summary article on each subject. These ten summaries are presented in the succeeding pages.

FUTURE PROCEDURE OF THE COMMITTEE.

It is obvious that the Committee has not drawn upon the full resources in ideas of the Society and that the mechanism of selection outlined above is too cumbersome for continued use. *We therefore solicit suggestions from all sources for our future guidance.* We will welcome suggested subjects for summaries or such summaries themselves. We will welcome ideas that will further research on ore deposits.

We hope to publish, from time to time, in the pages of this journal, other collections of subjects in an attempt to keep before the profession some of the fields that require further investigation, the projects going forward and the men working on them.

We hope that any geologist will feel free to initiate discussion or correspondence on matters which might concern the Committee.

Committee Members	*Consultants*	
C. H. BEHRE, JR.	H. M. BANNERMAN	ANTON GRAY
C. D. HULIN	A. M. BATEMAN	L. C. GRATON
EARL INGERSON	T. M. BRODERICK	W. O. HOTCHKISS
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W. H. NEWHOUSE	W. H. CALLAHAN	H. S. MCQUEEN
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	H. G. FERGUSON	F. G. WELLS

August 6, 1947.

W. D. JOHNSTON, JR.,
Chairman.

I. SERICITE-KAOLIN ALTERATION AS A GUIDE TO ORE.

T. S. LOVERING.

The hydrothermally altered wall rocks of many epithermal and mesothermal ore deposits are characterized by zones in which silica, sericite, clay minerals, and carbonate or sericite are successively prominent away from the ore. This horizontal zoning suggests that vertical changes may also be expected but this third dimension has been studied in few places. The se-

quence of alteration is commonly similar in different districts though quantitatively quite different, and usually the oldest alteration minerals are in the outermost zones. Thus, the paragenesis of the minerals is of especial importance because some minerals occur in more than one zone but have different age relations, which may be used to ascertain the zone represented. Presumably the changes in wall rocks caused by hydrothermal solutions differ greatly between the magmatic source and the surface outlet, and also differ at any given level with horizontal distance from a steep mineralizing conduit.

The space-time relations of the different types of alteration need much more study and they raise a series of challenging questions with every specimen examined: "Does it represent an early barren stage? Is it contemporaneous with ore deposition? Where does it belong with respect to the general locus of ore deposition? At the same level? On the outlet side? On the inlet side? On the outer fringe of alteration? Or close to a channel of mineralization?"

Much more petrographic study and field work are necessary before such questions can be answered with confidence. Among those who were making a serious study of such fundamental problems in recent years are: R. G. Bogue, New Jersey Zinc Company, Gilman, Colorado; C. M. Gilbert, U. S. Geological Survey; Paul F. Kerr, Columbia University, New York City, N. Y.; T. S. Lovering, U. S. Geological Survey; Charles E. Meyer, Anaconda Copper Company, Butte, Montana; N. P. Peterson, U. S. Geological Survey; C. S. Ross, U. S. Geological Survey; G. M. Schwartz, University of Minnesota, Minneapolis, Minn.

Further field study is urgently needed where underground openings allow observation of vertical and horizontal changes; such studies should be accompanied by careful petrographic and chemical work. There is also a great need for laboratory investigation of hydrothermal alteration—studies of differential leaching of elements from complex rocks such as granite by different solutions, and more studies comparable to those made by J. W. Gruner of the synthesis and stability of different types of alteration minerals. Such investigations will be most helpful in the interpretation of our slowly accumulating data on hydrothermal alteration and its relation to ore.

II. Causes for the Selective Localization of Ore in Certain Limestone Beds.

JOHN S. BROWN.

This topic must be made broad enough to cover both true limestones and dolomites; it must also include non-crystalline and metamorphic types. Thus defined, it is a subject that long has fascinated economic geologists. Every mining district in which limestone replacement is important has its background of descriptive literature, and there have been a number of important attempts at synthesis. Probably few will object to the conclusion that, in spite of the apparent wealth of data, the exact controls that fix an orebody within a certain bed or portion of a bed have not been determined with any great measure of satisfaction.

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Past research usually has followed one of three paths:

1. The analytical-chemical path, seeking to establish some relation between a chemical characteristic and ore deposition. A favorite has been the degree of dolomitization, but others such as carbon or carbon-compound content, cherty or siliceous phases, and shaly impurities have been considered. On the whole, these studies have failed to establish any rule useful as more than an empirical guide in special situations.

2. The physical path, evaluating structural features. This, in turn, may be subdivided into two phases:

(*a*) Study of visible structures such as brecciation, bedding, joint planes and solution cavities.

(*b*) Study of invisible or microscopic characteristics, including microbrecciation, porosity and permeability. There is a tendency, at present, perhaps, toward concentration on this phase, and it is probably one that should be encouraged, although two fairly ambitious current efforts (Rove and Brown) seem to point somewhat toward the blind alley ending similar to the present situation along path No. 1. However, these two studies should give subsequent investigators good vantage points for further progress.

3. The experimental path, which naturally is another chemical approach. Past effort, not of any great extent, has been confined mainly to attempts to simulate replacement using aqueous solutions. The results, so far as known, have fallen far short of duplicating the natural phenomena of ores, but a thorough search of foreign literature might modify this conclusion slightly.

This reviewer believes this to be the most promising line of attack, and feels that it should be expanded to include high temperature and pressure conditions both with and without the assistance of water. For such a program the investigator should be equipped with a good knowledge of physical chemistry, provided this has not taught him too many things that cannot be done. He would also need fairly liberal financial backing and good laboratory facilities.

The accompanying selected bibliography and other references listed in the articles cited should give any beginner a fair idea of the background material already available.

REFERENCES.

Van Tuyl, F. M.: Origin of dolomite, Iowa Geol. Surv. 25: 251–422, 1916.

Hewett, D. F.: Dolomitization and ore deposition, Econ. Geol. 23: 821–863, 1928.

Hayward, M. W., and Triplett, W. H.: Occurrence of lead and zinc ores in dolomitic limestones of northern Mexico, A. I. M. E. Tech. Pub. 442, 1931.

Bain, G. W.: Mechanics of metasomatism, Econ. Geol. 31: 505–526, 1936.

Brown, J. S.: Factors of composition and porosity in lead-zinc replacements of metamorphosed limestone, A. I. M. E. Tech. Pub. 1194, 1940.

Rove, O. N.: Some physical characteristics of certain favorable and unfavorable ore horizons, Econ. Geol. 42: 57–77, 1947.

Brown, J. S.: Porosity and ore deposition at Edwards and Balmat, N. Y. To appear in Geol. Soc. Am. Bull., 1948.

Also see topic of Experimental Replacement in Geol. Soc. Am. Bibliography of Geology, Exclusive of North America, esp. 1937, 1938 and later.

III. Volcanic Emanations as Keys to Ore Transport.

C. S. ROSS.

The relationships of ore deposition to volcanic activities, including the effects of gases, vapors, and thermal waters, have long interested those who seek to understand the processes of mineralization. Volcanoes have been a subject of interest by man since early time but the spectacular physical aspects of volcanism have tended to attract greater attention than the more prosaic chemical reactions. More recent studies have turned more toward this phase of volcanism and have provided much valuable chemical data, but the distribution of volcanoes, commonly in difficulty accessible regions, their intermittent activities, and the problems presented in the collection of their gaseous emanations make progress slow. However, intensive studies of the various phases of volcanic activity are under way in many parts of the world, and in a few of these detailed day-by-day observations have been continued for long periods. By these studies the gap between the surficial processes of volcanism and the deep-seated ones of ore deposition are being narrowed. For instance the deposition of a large group of elements from volcanic gases has been exhaustively studied by Zies, at Katmai; Lacroix, Zamborrini and others have presented a large amount of information about the minerals of Vesuvius; members of the Geophysical Laboratory have made detailed studies at the Yellowstone geyser region; Fenner has made a valuable study of mineralization in bore holes in that region; Shepherd has studied the gases of Hawaiian volcanoes. Geologists, among them, Lindgren and Weed, have studied mineralization related to hot springs, and intensive studies are under way at Steamboat Springs, Nevada. The studies of Fouqué and Deville were early but valuable contributions to our knowledge of volcanic emanations.

Studies of volcanic processes are being made on fumaroles, geysers, hot springs and bore holes in areas of waning volcanic activity. These include studies of the chemistry of the gases, vapors or waters evolved, their temperatures, their chemical effect on rocks and minerals, and the solid materials being deposited. Geysers, hot springs and bore holes probably deserve more intensive studies than they have so far tended to receive, as the information they give supplements that of volcanoes. Bore holes in particular provide unusual opportunities for the study of the effects of thermal waters and vapors. It is recognized, however, that the temperatures and pressures encountered present serious difficulties. Although hot springs, geysers and bore holes present only the surficial and attenuated end phases of magmatic activity, they probably represent a more direct line of descent from ore forming processes than do some of the more spectacular activities of volcanoes.

Geysers and hot springs, being surface or near surface phenomena are characterized by such low pressures and temperatures that they have dropped most of any load of metallic materials which they may once have carried. Nevertheless even minute traces of elements which they carry have significance particularly of those elements which are believed to be in general, the ones which are deposited early in the mineralization sequence.

Volcanoes, fumaroles, and hot springs do not normally yield ore deposits of commercial value but they provide information of fundamental significance, information which no other forms of geologic activity can provide, for they are almost the only phenomena bearing on ore deposition that can be directly observed. The student of ore deposits cannot directly observe their formation and is primarily interested in the geologic and mineralogic relationships involved, and from these attempts to deduce genetic processes. On the other hand the volcanologist observes processes and from these attempts to determine geologic and mineralogic relationships in zones lying beyond direct observation. Thus the two lines of research supplement one another. It seems evident that these two regions of observation may be extended and interpreted so as to provide information which will do much to solve some of the fundamental problems of mineral genesis.

The studies of volcanoes, fumaroles, hot springs, geysers and bore holes have inherent limitations, some of which may be mentioned, not to disparage the approach by means of volcano studies, but to suggest some of the factors which may be most productive. Many active volcanoes of today are basaltic in character. Basaltic rocks and even their deep-seated equivalents, diabases and gabbros, seem with a few notable exceptions to be less important as a parent source of mineral deposits than are the more silicic types of rocks and in general they are lower in volatiles, which are commonly believed to play an important role in ore segregation and transportation. However, some basaltic eruptive centers are explosive in character, due to a high concentration of volatiles, and are a source of information about these materials. The question arises as to whether these are representative of volatiles in general. Is there a systematic difference in kind and amount of volatiles derived from the different types of rocks, or are the differences in volatile emanations and the materials carried by them dependent upon the progressive stages of volcanic activity? The Tertiary was a period during which many of our ore deposits were formed, and there is doubt that ore deposits of equal importance are being formed at the present time. If this is so, how does it affect conclusions based on studies of existing volcanoes, particularly of rhyolitic and related eruptions which do not seem to duplicate the stupendous ones of Tertiary time?

Only a few of the interrelations of ore deposition and volcanic processes, and possible methods for their study can be touched upon in a short resumé. However, none are more important than prompt and systematic study. No part of the problems will need more intensive studies by means of all the sciences than the correlation and interpretation of all data that can be adduced from the several modes of approach. The student of ore deposits can play his part by helping to bring into effective coordination the two fields of observation, and in so doing contribute not only to his own science, but also to that of vulcanology.

REFERENCES.

Deville, Sainte-Claire, and Leblanc, Felix: Mémoire sur la composition chimique des gaz, pp. 63, Paris, 1858.

Fouqué, F.: Eaux thermales L'Ile de San-Miguel Açores, pp. 150, Lisbonne, 1873.

Fouqué, F.: Santorin et ses éruptions, pp. 433, Paris, 1879.
Weed, Walter Harvey: Mineral vein formation at Boulder Hot Springs, Montana, U. S. G. S. 21st Ann. Report, part 2, pp. 233–255, 1899–1900.
Lindgren, Waldemar: The hot springs of Ojo Caliente and their deposits, ECON. GEOL. 5: 22–27, 1910.
Day, Arthur L., and Shepherd, E. S.: Water and volcanic activity, Bull. Geol. Soc. Am. 24: 573–606, 1913.
Allen, E. T., and Zies, E. G.: A chemical study of the fumaroles of the Kalmai Region, Kalmai series, No. 2, pp. 75–155, 1923.
Zies, E. G.: The fumarolic incrustations and their bearing on ore deposition, Nat. Geographic Soc. Contrib. Tech. Papers, vol. 1, No. 3, pp. 157–179, 1925.
Zies, E. G.: The fumarolic incrustations and their bearing on ore deposition, Kalmai series, vol. 1, No. 4, part I, pp. 1–61, 1929.
Zies, E. G.: The acid gases contributed to the sea during volcanic activity, same series, vol. 1, No. 4, part II, pp. 61–79, 1929.
Allen, E. T., and Day, Arthur L.: Hot springs of the Yellowstone National Park, Carnegie Inst. of Washington, pp. 1–515, 1935.
Zambonini, Ferricio: Mineralogia Vesuviana, 2nd edition, Rosenberg & Sellier, Torino, 455 pp., 1936.
Fenner, Clarence N.: Bore hole investigations in Yellowstone National Park, Jour. Geol., vol. 44, part II, pp. 225–315, 1936.

IV. COMPARISON BETWEEN "PRODUCTIVE" AND "BARREN" IGNEOUS ROCKS.

A. F. BUDDINGTON.

The problem "Comparison between 'Productive' and 'Barren' Igneous Rocks" is one upon which literature directed specifically and systematically to its elucidation is meager, though much has been written on the subject of correlation of specific kinds of mineralization with specific kinds or specific complexes of igneous rocks and structural control has been proposed to explain the restricted localization of mineralization around a given intrusive mass. Certain outstanding problems have been stated, such as: Why should there be such relatively insignificant ore mineralization in the New England states where there has been such a long and complicated history of intrusive magmas during the Paleozoic? With all the variety and magnitude of intrusions of the granite family in the United States why should there be such insignificant tin mineralization? and Why has over 95 per cent of all the gold so far found in the Canadian shield come from the Algoman area, most of it in association with Algoman intrusives?

Possible suggestions as to the reason for "barren" versus "productive" igneous rocks have been: (1) "unfavorable intensity conditions" as for example, too high temperatures and pressures for deposition of metalliferous minerals, under deeply eroded batholithic conditions, as compared with favorable conditions around "apically truncated stocks"; (2) "unfavorable metallogenetic province" which is a way of implying that in certain regions the solutions derived from the magma lacked adequate metalliferous compounds due either to lack of the appropriate compounds in the parent magma, to lack of the right kind of volatile (B, F, Cl, etc.) to form a volatile or hyperfusible compound with the metal and thus permit its concentration and removal, or to unfavorable conditions for concentration by differentiation, etc.; (3) "unfavorable structural conditions" which may be consequent upon the country rock being unsuitable to carry the right kind of fractures and faults or to the

potential channelways not being developed at the right time, or to their not extending sufficiently deep to tap an ore-bearing solution assumed to have differentiated from the magma to accumulate at the roots of an intrusive center, or to the type of deformation being of the wrong kind; (4) "unfavorable country rocks," those of a composition, texture and structure unsuitable to induce precipitation, undergo replacement, or carry appropriate channelways, and (5) "unfavorable conditions of differentiation" whereby even though there were adequate metalliferous compounds in the magma, they were not concentrated in appropriate differentiated solutions—perhaps the metal ions are fixed as a widely distributed and diffused ("camouflaged") trace element in certain common minerals throughout the igneous rock under appropriate conditions of depth, imperviousness of cover, rate of cooling and mode and course of crystallization and fractionation rather than concentrated in outgoing solutions.

A review of the suggested origins emphasizes the imperative need for more geochemistry and more geophysics (in the sense of knowledge of the properties and reactions of rocks under different physical conditions and of the flow of ions, atoms and fluids through them). We need more quantitative mineralogical and chemical data for major constituents of both "productive" and "barren" rock complexes in order to compare them more definitively and we need more experimental geochemistry. We especially need a tremendous increase in quantitative chemical data on the amount of minor constituents in the igneous rocks of "productive" and "barren" complexes, in various country rocks and in volcanics as compared with hypabyssals and plutonics.

V. Geochemistry and Localization of Dolomitization.

CHAS. H. BEHRE, JR.

How dolomite and related epigenetic carbonates come to be formed in rocks and what is the significance of their formation genetically and in the search for ore are the key questions considered in this digest. The related subject of causes for ore localization in carbonate rocks is discussed on a preceding page by Dr. J. S. Brown.

Widespread Nature of Carbonatization.—The occurrence of carbonates of the kind possibly related to ore deposition is widespread; the physical chemistry of their origin has, so far as the writer is aware, been discussed only very generally.[1] Distribution of epigenetic carbonates varies greatly: In some districts it is widespread and thus has stratigraphic value; elsewhere it is strictly local and cuts sharply across the beds. A few examples only can be cited in this space. The Silesian zinc district [2] and the Leadville district in Colorado [3] are illustrations of the former type; the Goodsprings district in

[1] Rastall, R. H.: Physico-chemical Geology, Longmans Green & Co., London, 1927, pp. 191–197. Eitel, Wilhelm: Rhysikalisch-chemische Mineralogic und Petrologic, Verl. v. Theo. Steinkopff, Dresden, 1925, pp. 130–132, etc.

[2] Seidl, Kurt: Die oberschlesische Zinkerz lagerstätte, Zeitschr. d. oberschl. Berg- u. Hütten m. Vereins, 66 Jahrg., Heft 11, pp. 694–695, 1927.

[3] Emmons, S. F., Irving, J. D., and Loughlin, G. F.: Geology and ore deposits of the Leadville mining district, Colo., U. S. Geol. Survey Prof. Paper 148, pp. 35–36, 1927.

Nevada,[4] the Alpine zinc deposits of Austria, Italy, and Jugoslavia,[5] and the ore region of Iglesias in Sardinia [6] illustrate the more sporadic, highly localized pattern. These two extremes represent variously rocks that receive their unusual ions while being deposited as sediments or developed them penecontemporaneously or during diagenesis (all of which may be called "penesedimentational" dolomite); and, at the other extreme, rocks in which the unusual elements were introduced later, in part perhaps during ore deposition ("penemineralizational of dolomite). A third type seems implied by some cases in the Southern Appalachians where dynamic factors apparently controlled distribution of the dolomite in otherwise magnesium lean carbonate rocks.[7] Finally, epigenetic carbonatization is also recognized, though less widely, near ore deposits in arenaceous rocks, as in the Coeur d'Alene district,[8] at Mechernich and Commern in the Rhine valley,[9] and elsewhere, and even locally, like the recently studied clay and mica minerals, in porphyritic and other igneous rocks.

Nature of Carbonates.—Not only dolomite, but ankerite, siderite, manganosiderite, and similar minerals are common in the "penemineralizational" carbonates. One striking feature is the common change in these gangue minerals from dolomite to more iron-rich minerals as the vein or alteration is followed from a Ca- or Mg-rich country rock to a slate or, less commonly, a quartzite. This suggests the derivation of the positive ion of the carbonate from the country rock itself.

Criteria for "Penemineralizational" Carbonates.—How can the epigenetic carbonates associated with ores be distinguished from the primary carbonates of ordinary limestones or of "sedimentary" dolomites? When the new (?) carbonate is widespread at a given horizon it is assumed to be essentially sedimentational, but geologists familiar with the remarkably pseudo-stratigraphic distribution of certain ores that are clearly epigenetic are justly skeptical of this criterion. Fracture fillings or masses that cut across the beds are obviously secondary. In some instances later (clearly "penemineralizational") carbonate gangue shows different crystal forms than an earlier phase of the same mineral (*e.g.*, rhombohedral forms versus dogtooth spar), but this criterion is seldom applicable in recognizing "sedimentary dolomites."

[4] Hewett, D. F.: Geology and ore deposits of the Goodsprings quadrangle, Nevada, U. S. Geol. Survey Prof. Paper 162, pp. 57–67, 1931.

[5] Beyschlag, F., Krusch, Paul, and Vogt, J. H. L.: Die Lagerstätten der nutzbaren Mineralien u. Gesteine, Verl. v. Ferd. Enke, Stuttgart, 1921, pp. 276, 279.

[6] Hewett, D. F.: Dolomitization and ore deposition, ECON. GEOL. 23: 839–840, 1928.

[7] Crawford, Johnson: Structural and stratigraphic control of zinc deposits in east Tennessee, ECON. GEOL. 40: 411, 1945 (not discussed in detail). Oder, C. L., and Miller, H. W.: General stratigraphy of the east Tennessee zinc deposits (abstr.), ECON. GEOL. 40: 600, 1945. In the district referred to, similar suggestions have been made by John Rodgers, D. F. Kent, Arnold Brokaw, R. A. Laurence, Josiah Bridge, and others. See also Hayward, M. W., and Triplett, W. H.: Occurrence of lead zinc ores in dolomitic limestones in northern Mexico, Amer. Inst. Min. Eng., Techn. Publ. 442, 1931. Park, C. F.: Geology and ore deposits of the Metaline quadrangle, Washington, U. S. Geol. Survey Prof. Paper 202, pp. 41–47, esp. p. 47, 1943.

[8] Ransome, F. L., and Calkins, F. C.: The geology and ore deposits of the Coeur d'Alene district, Idaho, U. S. Geol. Survey Prof. Paper 62, pp. 95–99, 1908.

[9] Blanckenhorn, M.: Die Trias am Nordrande der Eifel zwischen Commern, Zülpich, und dem Roerthal, Geol. Spezialkarte von Preussen und Thüringen. Staat., B and C, Heft 2, 1885.

A definite localization of a given carbonate (*e.g.*, dolomite) to the close neighborhood of the ore rules out its "sedimentary" origin, as shown in the Tri-State district by Fowler and Lyden and more lately in greater detail by others.[10] Recently the American Association of Petroleum Geologists has initiated a promising study of dolomitization by W. C. Imbt and R. K. DeFord.

Geochemical Implications.—Although the hypogene origin of the carbonates here discussed is widely accepted, the metal ions involved may be in part at least derived from deeper horizons, as suggested by Hewett,[11] Loughlin and Behre,[12] and others. The possible role of these metal ions in aiding transportation of base metals later deposited farther on as sulphides is also of interest, though paragenetic evidence suggests that the carbonates immediately associated with the ores are somewhat earlier or slightly later, rather than contemporaneous. If it occurs, this aid to transportation may be in complexes, not unlike those suggested by Garrels[13] for halides, but here instead as double metal ions.

Problems for Research.—From these considerations arise many questions meriting research. Conspicuous among them are the following. (1) Are the carbonates contemporaneously *in solution* with the ores but merely *precipitated* earlier or later? (2) How distinguish "penesedimentational" from "penemineralizational" carbonates, especially in the case of the dolomite? (3) Why do the metal ions of carbonate gangue minerals change when the rock changes? (4) Does the replacement of carbonate rocks by carbonate gangue furnish any indication as to the nature of the mineralizing solutions? (5) Are the carbonate ions and the metal ions so commonly appearing in ore districts to be viewed as magmatic or merely as redeposited from lower horizons? (6) Why are dolomites so common with lead, zinc, and copper, so rare with tin, tungsten, and antimony ores? (7) Were the metal ions now in the carbonate gangue perhaps once instrumental in base-ore-metal transport needed for the lead-zinc-copper deposits?

Basic chemical study of the reactions of CO-CO_2-Ca-H_2O systems is needed, as well as similar investigations with Mg, Fe^{II}, and Mn^{II} as the alternative metal ions. From geologists and mineralogists more detailed observations on these changes are desired. These problems have both theoretical interest in connection with ore genesis and a practical value in following the distribution of epigenetic carbonates as clues to ore distribution.

[10] McKnight, E. T., Fischer, R. P., Addison, C. C., Bowie, K. R., Thiel, J. M., Owens, M. F., Jr., and Wells, F. G.: Map showing structural geology and dolomitized areas in part of the Picher zinc-lead field, Oklahoma and Kansas, U. S. Geol. Survey Tri-State Zinc Lead Investigations, Prelim. Map Sheets 1–6, 1940.

[11] Op. cit., p. 67.

[12] Loughlin, G. F., and Behre, C. H., Jr.: Classification of ore deposits: Ore deposits of the Western States (Lindgren Mem. Vol.), Amer. Inst. Min. Eng., New York, 1933, pp. 40, 54.

[13] Garrels, R. M.: The Mississippi Valley type lead-zinc deposits and the problem of mineral zoning, ECON. GEOL. 36: 735–740, 1941.

VI. Detailed Studies of Zoning in Ore Districts.

ROLAND BLANCHARD.

The concept of zoning postulates that, with progressive changes during cooling of the hypogene ore fluid, sulphides and other ore minerals and their accompanying gangue associates for a given district separate out in a well defined sequence. The zonal arrangement or pattern may find expression in a lateral or vertical plane, or both. The phenomenon is conceived as controlled mainly by temperature and pressure—minerals of the outlying zone being deposited characteristically at low temperature and pressure, those of the intermediate zone at intermediate temperature and pressure, those nearest the ore fluid's source at moderately high temperature and pressure. Some sponsors stress as of nearly equal importance such factors as relative solubilities, decreasing electrode potentials, decrease in sulphur content, and other physical constants of the respective minerals.

Several world-famous ore districts reveal the zonal pattern almost flawlessly; most districts reveal it in partial or modified form; and geologists are in general agreement that the hypothesis of zoning furnishes the most convenient and useful framework yet proposed as a background perspective upon which to hang the field facts of ore occurrence.

Few districts, however, fail to disclose at least one or more major violations of the paragenetic sequence, or of the zonal pattern, as postulated by the concept. For the mineralized districts considered as a whole, transgressions are frequent, varied, and in some cases flagrant, and over a number of districts involve every mineral in the ore column.[1]

Because of the idealized picture afforded by the idea of zoning, with the assurance of finding the zonal pattern expressed at least in part in nearly all mineralized districts, an unfortunate tendency has developed among some geologists to regard such zoning as an established routine in ore deposition. Accepting it as such, too often they have been content merely to note the conformances without carefully adducing supporting criteria, and without determining critically whether the conformance be superficial or real. For the same reason, many have been content to ignore the inconsistencies and contradictions, or to dismiss them as fortuitous. The attempt to dismiss a contradiction as fortuitous implies, at best, a disinclination to grapple with realities. In consequence there has accumulated gradually in support of the hypothesis a body of unauthenticated or spurious "evidence," rendering more difficult the hypothesis' ultimate impartial assessment.

By way of illustration, there has not been in all cases a determined attempt to ascertain whether a given mineral occurs in zonal position as the result of progressive changes in composition during cooling of the ore fluid, as called for by the zonal hypothesis, or whether its occurrence at that place has been the outcome of stratigraphic or structural control; just as in other

[1] Excluded from consideration, by common consent, are deposits which have experienced more than one general period of ore deposition, deposits in which well defined telescoping has been established, and deposits localized along structural freaks. Absence from the column of a given mineral, as also blank areas between successive minerals, likewise is conceded for a given district.

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cases such controls are known to have enticed a given mineral from its postulated zonal habitat. Until doubt has been removed as to the ore having been localized by such controls, mineral zoning, by definition, cannot be regarded as established at those places.

Again, in one famous silver-lead-zinc district, high silver content characteristically favors the synclines. Increase in silver content with depth in the major synclinal trough, by the same token, cannot be construed as a contradiction to zoning (as it has been done by at least one geologist), however compelling may appear the isolated facts of occurrence.

In another major district where both minerals are mined importantly for ore, cassiterite increases over wolfram in depth, despite well established paragenetic priority of the latter mineral over the former. Relative saturations of the two minerals within the ore fluid are believed in this case to account for the paragenetic contradiction despite conformance to the zonal pattern.

Confusion has arisen further, in some instances, through focusing upon concentrations of a given mineral which, by man's arbitrary and capricious standards, are classed by him as ore; as opposed to considering total volume of the mineral in the district, including that dispersed leanly but pervasively through the country rock at other horizons.

These examples suffice to show that careful determination of both the paragenetic and field relationships, and caution in their appraisal, are needed lest mere accidents or end results in ore deposition be confused with its processes.

Similarly, districts may be cited in which two or more intrusive stocks are known, each with its characteristic content or aureole of the ore minerals. Though of a single age, it is hardly to be expected that multiple stocks necessarily would have attracted to themselves, from the ore fluid reservoir, identical ore constituents; or that identical constituents, if available, necessarily would have found emplacement in corresponding patterns and concentrations. The expectation certainly is not born out by observations in districts where multiple stocks are known. Yet an omniparient and omnipresent ore fluid at any particular stage in ore deposition is a basic assumption of the zonal hypothesis.

On the other hand, in districts where only one stock is exposed or indicated, but where mineralization is dispersed broadly through the invaded rocks, what is the chance that undetected multiple ore loci of the sort described may have been operative, to mislead the observer either in confirming or challenging the zonal concept?

The value of the concept lies not in post-mortem verdicts of worked-out mining districts, but as a living tool to be applied in the search for ore in districts still vigorous and active. Applied in its present state to such districts, save in a few favored cases, the concept too often, unfortunately, has proved misleading and costly, out of all proportion to the occasional success which it has scored.

For precipitation to take place progressively in conformance with the zonal hypothesis the following rather idealized set of conditions seems called for: (*a*) an omnific ore fluid emanating with an approach to uniformity from

one general locus in proximity to the zonal column's base; (*b*) a pervious channelway through which the ore fluid continues to move, and one which provides gradual and uniform escape of the mineralizers progressively upward and outward from that locus; (*c*) sufficient uniformity of structure and homogeneity of rock type to eliminate or reduce to small proportions the tendency for a given mineral to be lured from its postulated zonal habitat through affinity for a particular structure or rock type; (*d*) sufficient quantitative balance or adjustment among the various constituents within the ore fluid to maintain equilibrium until the proper temperature-pressure conditions favorable for precipitation of each mineral in the column is reached.

Because few developed mining districts yield evidence of having furnished so ideal a set of conditions as to ore fluid composition and precipitation-favorability, the conviction has grown among an increasing number of geologists that, in its deposition of the ore minerals, nature employs controls of a broader range and greater degree of flexibility than are encompassed by the hypothesis of mineral zoning in its present form.

So far as the writer is aware, no geologist today is studying the problem of mineral zoning in all of its aspects, or on a continuous basis. Many are making careful studies of it in particular districts as opportunity permits, with a view to ascertaining the detailed paragenetic and zonal behaviors for the deposits at hand. Through such studies much has been found both to support and to challenge the concept of zoning as it now stands. However, through lack of time, or inclination, or because the data have not seemed sufficiently complete to justify presentation, much of the information known to have been already acquired, by commercial geologists in particular, remains unpublished.

In order that the hypothesis of mineral zoning may be suitably evaluated, its sound features confirmed and more fully elucidated, and where necessary the premises upon which it rests broadened so as to enable its possibilities as a guide in the search for ore to be more economically and fully realized, there is need for an earnest, judicial, and far more detailed study of its expression in most of our mining districts than has been accorded it in the past; for a more liberal presentation for the benefit of others of their work by geologists who have achieved pertinent results relating to the concept; and for an objective re-examination of the published literature to ascertain the degree to which assertions of zonal expression have been based, in the past, upon adequate factual evidence on the one hand, and upon incomplete observation, faulty emphasis, or mere assumption, on the other.

VII. Expansion of Geophysical Methods Applicable to Ore.

ROLAND F. BEERS.

There is little doubt that research and development are required for improved rates of discovery of ore deposits. It is generally realized that geophysical developments leading to petroleum discoveries have been carried far beyond those of ore exploration in extent of application, breadth of coverage

in pertinent scientific fields, and depth of penetration in any single field. It is probably true that the variety and complexity of the geologic settings in ore deposits remaining to be investigated by scientific tools exceed those of the petroleum domain. The opportunity and hope for improved rates of discovery through further application of known scientific principles are therefore exceedingly great.

In attempting to formulate a program of research and development to problems of ore discovery, it is necessary first to recognize certain features of the industry supporting the execution of such a program. With the exception of a few outstanding examples, it is customary for the effectiveness of geophysical exploration techniques to be judged by the amount of ore discovered. For more than 25 years this method of evaluation has limited the development of new methods. This point of view is not scientific, and if improvement is expected from these methods, it is important to recognize that a great many fundamental investigations must first be completed before direct exploration techniques will be available. There are many ways in which the employment of geophysical techniques will enhance the knowledge and understanding of ore deposition. In general, the most effective techniques are likely to be indirect, leading not to the discovery of ore itself, but to the delineation of structural, stratigraphic, mineralogical and geochemical factors from which clues to the location of ore may be derived.

In the past, slight opportunity has been available to compare the results of geophysical exploration with subsequent development of ore bodies. If trial and error are to be of value, it is important to analyze successful and unsuccessful programs of exploration without discrimination. In many cases exploration campaigns which fail to find ore may lead to valuable improvements in the art of exploration. Geophysical aids to the development of ore bodies may throw valuable light on new concepts and ways of finding ore.

If the occurrence of ore is related to geologic structure, it would be of value to obtain information thereon by the use of the seismograph and certain electrical methods. Instruments and their use for seismic explorations are fully developed throughout the petroleum industry, awaiting only the opportunity of application to problems of structural delineation related to ore bodies. Depth of overburden, attitudes of bedding planes, dikes, veins, and folds can be determined with sufficient accuracy by geophysical methods to warrant subsequent action with the core drill, pitting or trenching. Faults can be outlined accurately by seismic, electrical and electromagnetic techniques unless the structural details are too complicated to permit unique interpretations.

In all phases of geophysical exploration it is imperative that the surveys be conducted with complete geological knowledge of the area under investigation. Only the full integration of all points of view will yield adequate returns from this field of endeavor.

Development of special techniques for exploration will be successful if applications are made to specific problems against the background of comprehensive geological knowledge. By preserving the point of view outlined above, definite advances might be expected in specific techniques. For example, when the structure of the Illinois lead-zinc district has been mapped

in detail by surface and subsurface geology, the seismograph might be employed to determine its full scope and limitations. The successful operation of the seismograph in such a problem requires a full knowledge of actual structural conditions, independently determined by geologic mapping, an appreciation of the principles of structural geology involved, and an adequate working knowledge of the service which the seismograph might be expected to render. Success in this problem thus depends upon the availability of fundamental knowledge, geologic facts, informed personnel and adequate equipment. The combination of these elements is rare, but only through such combination can the utmost in geophysical exploration aids be expected. Similar problems require solution to which may be applied existing equipment now serving in other fields. The airborne magnetometer, the gravity meter, electrical and electromagnetic instruments are available to the mining industry for fundamental research. If applied to specific prospects under rigorous geological supervision, these methods will bring to light data valuable to prospectors for new ore deposits.

VIII. Causes for Downward Limits of Hypogene Deposits.

L. C. GRATON.

INTRODUCTORY COMMENTS.

The assigned subject is manifestly one of importance. With the progressive and accelerating exhaustion of known ore reserves over the world, a great fraction of future supply will unquestionably come from deepening the mines in districts where conditions favorable to hypogene ore deposition have already been abundantly demonstrated. The great majority of mines on hypogene ores are as yet less than half as deep as the greatest depth to which successful ore extraction has already reached. This present record is surely not the final extreme, even though there is reason for believing it to be more than half of what the eventual limit will be. Below the present lowest workings of most hypogene districts, then, there still remains a greater thickness of potentially ore-bearing ground that could be mined than the slice already explored.

Granted that in many, even possibly a majority, of the presently known districts the incentive to continue exploration downward will not persist to the depth that represents the physical limit of mining, it is nevertheless obvious that an important factor in weighing the incentive will be the geological chance of ore occurrence below existing bottom levels. It is plainly upon the geologist that the obligation devolves of appraising such geological chances. Under this responsibility he cannot fail to be profoundly interested in all the causes for downward limits of hypogene ore occurrence, in order that we may most wisely decide, when known ore ceases downward, whether this probably represents the ultimate downward limit of commercial ore, or whether to recommend deeper exploration.

To achieve the Committee's purpose of presenting a sort of target to

stimulate and focus the further thinking, observation and research on this subject by many workers, a broad and judicious approach is necessary—the predilections and aversions of the one designated to assemble the target must not be overworked. The present writer has nevertheless taken the liberty of setting forth, in footnotes, a few entirely personal comments.

The problem presented is so comprehensive and complex as to have probably no royal road of approach immediately obvious and acceptable to all workers. The present attempted outline may thus be far from the desired mark. Anything like specific and inclusive listing of topics of research seems quite out of the question. An analysis to explore the limits of the problem and perhaps to help avoid ambiguity among those who deal with it may be found of some utility. Portions of the discussion that may perhaps be more definitely suggestive of what may be done and how are indented from the left margin.

ANALYSIS OF THE PROBLEM.

1. *Geologico-Economic Control.*—It is essential from the outset to bear in mind that the position of ore boundaries is generally governed by two independent variables, geologic and economic. Where geological process and condition long since left their changeless influences is superimposed the criterion of profit, which fluctuates from year to year. Thus no intrinsic and eternal rules of ore persistence may be assumed to exist, even in a single occurrence. The repeated revival, through the centuries, of previously "worked-out" districts confirm this. Moreover, even within a generation what was waste may become ore with new and abler management; or the reverse may be caused by excessive wage demands, taxation or governmental restrictions. Among the many inherent factors affecting profit, those of rock pressure, air temperature, time-distance for hoisting, pumping and ventilation, and exploratory effort per unit discovered all tend toward increased costs for deep levels, and thus especially impinge on the problem of downward persistence.

2. *Downward Discontinuity Normal.*—Because metal concentration of economic tenor results from the localized coincidence of numerous favoring conditions, some of them probably extremely sensitive, and because mining tries to start with and to follow the richest ground, it is statistically almost inescapable that dimensional expansion of operations shall eventually encounter declining grade. This deterioration of grade proves to occur downward as well as in other directions, even in ores supplied from below, hypogene; and our theories are more or less unconsciously though imperfectly adjusted to this empirical situation. Because of the economic factors that selectively burden deep operation, as in (1), downward persistence of what can be accepted as ore is doubly susceptible to adverse change. It is inevitable that inquiry as to downward persistence and downward limits of ore deposition must give close attention to the conditions and causes locally operative where a body of minable ore ceases downward.

3. *Adequate Exploration of Depth.*—Conditions favoring the deposition of hypogene ore in any given locality rarely so operate as to produce only a single

ore body or shoot. Very commonly, instead, among the numerous ore bodies that constitute "the district," some are found, *on adequate exploration,* to lie deeper than others that have bottomed somewhere above. Inasmuch as the assigned title is a subdivision of the Committee's broader topic, "Zoning," discussion here should obviously relate to conditions more general and absolute than the bottoming of any given body or shoot. The real quest, presumably, is for the causes of *final* bottoming of the *district* with respect to ore yielding a given minimum profit. But "adequate exploration" is incapable of standardized specification applicable to all cases. The frequence with which epigenetic hypogene ore bodies, especially those due to replacement, are regarded as worked out without having disclosed their feeders from below implies either inadequate criteria for recognition of the feeders or inadequate exploration. The situation might be expected to be better for the many cases in which the feeding channelway, though no longer carrying commercial values, plainly continues on below the bottom of a given shoot, the usual condition in veins. Yet, in different districts, or even in the same mine, the profitless gap between a given body and the one next deeper may be slight or great; it is impossible to know in advance what the *maximum* [1] gap may be. Therefore, in any mine with worthless bottom level(s), only subjective standards decide whether exploration has been sufficient to eliminate *all hope* for deeper ore. If there still be hope, then the under boundary of the deepest known ore dare not be regarded as marking the downward "limit" for that locality.

4. *Clarification of "Downward" Direction.*—It seems clear that the terms "below," "downward," "bottom," "in depth," etc., must be interpreted quite freely if "adequate exploration" is to be achieved. The common tendency to assume, perhaps almost subconsciously, that the depositing solutions in tabular fractures moved directly *up dip* naturally leads to most intensive exploration directly down dip from ore that has been bottomed, with corresponding slighting of ground on either side. This is especially likely to happen if the axis of maximum extension of the shoot that has bottomed points directly down dip. Or, if the long axis of the bottomed shoot lies oblique to the dip, search at a lower horizon is likely to favor the region of projected continuation of that axis. Before dependence may be safely placed on the extremely simple assumptions tacitly made in such cases as these, much more must be learned about the real direction(s) of flow in loci of permeability and about the causes and conditions of ore deposition. As regards only the *direction of flow,* such questions as these seem pertinent:

Is the axis of maximum permeability and thus of major flow likely in the average case to be ideally aimed up dip; or is the up-dip direction only the statistical average of great numbers of individual cases in which, because of structural vagaries, the axis of flow deviates more or less widely from this ideal, up-dip direction?

Does the direction of flow, if known or reasonably inferred in part of the channelway, hold steady above and below that locality; or, on the other hand, may flow follow a most devious and erratic pathway, so that rectilinear projection from any known stretch would be wholly unsafe?

[1] In regions where extreme topographic relief favors deep exploration by adit (*e.g.* Casapalca and Ouray), great gaps have the best chance of becoming measurable through discovery of deep ore shoots.

Does the direction of flow at any spot hold steady with time, or may it fluctuate widely during the long period required for ore formation, through unequal plugging by deposited mineral or through various deformations during the mineralizing episode?

In a vein produced wholly by deposition in open space, dare it be assumed that an axis along which the veinstuff is thickest marks the line of greatest permeability and hence the axis of major flow; or if such advantage initially existed there, may it have been progressively destroyed by accumulating mineral deposition, so that if the valuable minerals were deposited relatively late in the sequence the resulting ore-shoot need not follow the axis of thickest vein; or, alternatively, does the final irregular width of vein afford no safe clue as to initial width of fracture-opening but express only the varying thickness of mineral deposited from place to place along a fracture whose initial width may have been either everywhere greater (by early intrusive spreading of the walls by the solution and their later collapse upon the irregular thickness of mineral filling) or everywhere less (by progressive, cumulative local "reopening" and filling of thinner fractures)?

If we could know the actual line of flow through that part of a channelway in which a bottomed ore shoot lies would we expect the particular lot of solution which flowed past and deposited that known shoot to have deposited one or more similar shoots farther down the flow-line; or should we assume, instead, that this particular lot of solution had been able to deposit the known ore shoot because it had conserved until there its valuable constituents by not depositing them lower down; that is to say, should search preferentially be made down along the *same* flow-line or along a *different* one?

Is the long axis of an ore shoot most commonly controlled by, and made coincident with, the direction of major flow; or is it often determined chiefly by other factors of deposition that may be disposed, and may thus place the axis of the shoot, at any chance angle to the direction of flow, with the result that exploration along projection of the shoot axis would be unsafe?

5. *Possible Determination of "Downward" Direction.*—In our present state of limited understanding, it seems quite unsafe to dismiss as idle or "merely theoretical" questions like those just listed. To explore diligently down-dip from a "bottomed" ore deposit that had, in fact, been fed from the side would be scientifically embarrassing and economically tragic. On the other hand, to give heed to such questions only to the extent of concluding that, in order to achieve "adequate exploration," probing must lunge blindly for great distances everywhere is both to waste resources and to shirk geological responsibility.

Two approaches to this problem appear to be available: (*a*), statistical analysis of information already available, and deductions from such analysis; and (*b*), directed observation and research to expand and improve the information on these subjects.

(*a*) *Statistical.*—Assembly of data from available mine maps and sections where two or more ore shoots are known within the same inclusive locus of control or favorability. Classification of size, shape and spacing of shoots. Attitude of long axis with respect to dip, to disclose whether axes of successive shoots tend to be in line, en echelon, zigzag, or haphazard. Do the individual shoots systematically change in size, shape, spacing, attitude and/or grade either down dip or along any other line? Are significant features of one shoot systematically repeated in other shoots—for example, if the lower portion of the uppermost shoot is, say zincky, is this same condition present in all other shoots; or do some of the shoots show this condition and others fail to show it, thus affording a possible grouping into two categories, and hence, perhaps, hints as to possible "axes of like conditions." Contouring of overall grade or metal ratios, of thickness, attitude or

structural nature, of significant mineralogy, texture or wall-rock alteration (to whatever extent these data may be available) may be applied whether the general ore locus contains a plurality of ore shoots separated by worthless gaps or is everywhere workable but of varying tenor, etc.

(*b*) *Research.*—If information of any of the general kinds exemplified by the list just cited is not already available for a given mine or district, observation and tabulation of any such features as promise to be revealing may be undertaken on a trial basis, to be continued if deemed so to justify, and dropped if not. To whatever extent direction of flow may be regarded as significant, wider varieties of tests should be made, in extension of the suggestive beginnings by Newhouse [2] and by Gordon Smith; [3] and any clues resulting from the experimental studies should be tried against field occurrence in some such manner as Stoiber [4] has employed the Newhouse thesis in a part of the Tri-State lead-zinc district. Particularly useful would be indices of flow-direction that could be applied to other cases than druses and near-euhedral crystal units. For so much ore occurs in solid masses, often with a paucity of good faces on the mineral grains; and to such material most of the criteria thus far proposed are of little or uncertain applicability. It would be highly desirable, also, to establish whether the assymetry of form and internal structure which Newhouse has observed for open-space growth will apply also to growth by replacement, where transport by immediately local flow is at a minimum and by diffusion is dominant.[5]

6. *Supposed Indices of Bottoming.*—A considerable aggregate of descriptive detail has been recorded as to observable geological features associated with

[2] The direction of flow of mineralizing solutions, ECON. GEOL. 36. 612–629, 1941.

[3] Lineage structure and conditions of deposition of pyrite, ECON. GEOL. 37: 519–523, 1942.

[4] Movement of mineralizing solutions in the Picher Field, Oklahoma-Kansas, ECON. GEOL. 41: 800–812.

[5] It would seem safe to assume that both the experimentation and the interpretation of flow direction in natural examples should be at once versatile, skeptical and rigorous. It is conceivable, for example, that the "upstream" or stoss exposure of a growing crystal may, in certain solutions, be fed enough more generously with those *growth-depressing* components (which tend to restrain development of the normal faces and thus modify the habit of the crystal—*cf.* Bunn, C. W.: Crystal Chemistry, p. 13, Oxford, 1946) than with the essential components to reverse the expected extra growth in the upstream direction. It is also entertainable that scattered nuclei forming in haphazard distribution on a surface may chance to be closer together in one direction than in the direction at right angles; in such case, growth fed by diffusion alone—that is, in a *stagnant* solution—would tend to elongate the shapes in the direction of greater spacing of the nuclei, and thus permit the false interpretation of *flow* in that direction. Pressure, and hence temperature, in the solution meeting the stoss side of a stationary protuberance will be higher than where the solution departs from the lee side; and for most of the ore-mineral components, lowered pressure (*Cf.* Gibson, R. E.: Effect of pressure on the solubility of solids in liquids, Am. Jour. Sci. 35A: 64, 1938) decreases their solubility and hence increases their tendency to precipitate; the same is true for lowered temperature. Therefore, where the velocity of flow is sufficiently rapid, maximum deposition might take place on the *lee* side. If there be special directional effects in growth by replacement, these may possibly be controlled not more by the direction from which the new solutes (to yield the metasome) are brought in than by the direction of disposal of the old solutes (derived from the breakdown of the protosome). These directions will presumably be determined by the respective concentration gradients of the two sets of solutes, and may vary in relationship to one another in different cases. Cavities and druses within the midst of ore very commonly exist because they have become virtually sealed off from the previous supply of mineral-bearing solution; flow should thus be at a minimum in these openings, and they should therefore be the least advantageous places for detecting flow direction. It is reasonable, but probably by no means necessary, that the direction of such flow as does take place through a cavity (vug or druse) that becomes isolated in an upbuilding mass of ore is the same as the general direction of major flow that deposited the greater part of the ore. Granted flow through cavities, no compulsion exists that there be *some given direction* of flow through every cavity, for that would invariably imply inlet and outlet on more or less opposite sides. It would appear that much yet needs to be learned before safe conclusions can be gained as to direction of flow. In the meantime, it is to be expected that dispassionate and objective effort to apply the available tests to any given locality will encounter great numbers of non-committal or contradictory instances.

the bottom *of certain ore bodies*. Among such features are minerals, colors, lusters, textures, structures and wall-rock character. Some one or more of these have been interpreted by the several observers as diagnostic, and in numerous instances have been regarded as signalling the "downward limits" *of ore deposition* for the respective localities.

It might be expected that, by now, certain generalizations would be emerging that might apply, or at least deserve trying out, in other instances than those individual cases for which one or another of the "indices" has been described. Little of the sort seems to be available. Instead, the existing record seems to hold little of common import. Even the importance now so widely ascribed to structural control leads to diversity rather than broad similarity of specific conditions. A few examples will serve to show the confused status of ideas.

Lusterless, "dead" quartz is taken by some as a bad sign; but others are worried by encountering massive ("bull") quartz tending toward vitreous.

Increasing tightness of ground is regarded as unfriendly; yet increasing vugginess or brecciation is not infrequently distrusted.

Splitting of veins downward into multiple branches is often classified as threatening; yet many good ore clusters have died about where multiple veins join downward into one or a few strong (but lean) units.

A good ore body lying in shattered ground capped by a tougher and less permeable barrier is, with surprising unanimity, ascribed to damming, impounding or slackening of the ore-depositing solution near where it encountered the barrier effect; the full consequences of such supposed throttling of flow, rarely[6] explored and appraised, may strain the logic so commonly invoked.

If a simple ore shoot widens downward with declining grade, the structure at the lower elevation is blamed for dispersing the available values through too great a width (and tonnage) of worthless matter; but if a simple shoot of ample width and tenor narrows downward with falling grade, the structure at the deeper position is called inimical to ore.

Obviously, operative causes for bottoming of one shoot may not be the same as those for another shoot; it is even entertainable that the *opposite* of the cause for one may be cause for another. Nor does the foregoing deliberately selected list by any means exhaust the supposed indices or symptoms of ore bottoming that have been presented. Granted that conditions such as those mentioned exist, singly or in some combination, in one or another locality, it seems evident, nevertheless, that our understanding of them is far from perfect, and that they might more appropriately be presented as observable details which may *possibly* have some degree of influence among the complex of causes for the bottoming of ore, instead of being offered as reliable indices of bottoming.

7. Validity of the Proposed Indices.—There appears, in fact, to be but little in the empirical but imputedly diagnostic features as yet reported which

[6] McKinstry (p. 116 of symposium: Some observations in ore search, T. A. I. M. E. 144: 1941) has pointed to certain of the weak spots in this thesis. Others might be added, such as: The implied contradiction of other and more probable manifestations of structural control, like those which indicate that the quantity of ore deposited at a given place is some direct (not inverse) function of the cumulative quantity of ore-forming material carried to or through that place by the moving solutions. If the barrier impedes or stops flow in the neighborhood just underneath it, what happens to flow further down along the same channelway, and why should ore deposition so often be favored only reasonably *near* the barrier?

convincingly denies possibility of recurring ore below. Nor, as a rule, do these features seem to differ markedly from those, in the same or similar districts, which attend the bottoms of bodies that have been proved to be underlain by other ore. Neither are these various conditions generally viewed seriously *so long as assays continue good.* Nor, finally is any instance conspicuously of record in which the geologist or the management has felt so confident that the given features, even when associated with persistently discouraging assays, marked the ultimate "downward limit" of ore as forthwith to recommend and execute no deeper exploration—*unless* no funds were available for such effort. As a rule, conviction of ultimate bottoming is *ex post facto;* it is reluctantly adopted after fruitless exploration to some arbitrarily determined greater depth executed with some arbitrary degree of thoroughness under increasing financial nervousness. And when at last bottoming has been regretfully accepted, the natural desire to explain it leads easily to—shall we say—rationalization of the means and criteria. It may be significant that geologists of rich experience in appraising mines of many kinds and environments seem to put restricted faith in many indices or criteria of the kind so often described. In this very connection of downward persistence of ore, Sales has recently said:

> Experience . . . has proved the futility of trying to apply criteria broadly, notwithstanding that certain factors appear applicable to individual ore shoots.[7]

On the same topic, Joralemon says:

> I can hardly recall an instance where mining development has reached the real root of the mineralization. . . . The question is not whether new ore bodies may be expected in depth, but whether they are worth hunting for. Mines are abandoned because they have come to the roots of the bank account, not of the ore.[8]

The importance is to be granted of keeping aware of the mounting odds in the gamble as mines deepen, and of trying to sense when the time has come to cry quits. But in such questions the economic considerations, strictly local and contemporary, greatly dominate over those of inherently geological nature.

8. *How Deal with Indices?*—After all, our present capacity to deal with the problem of downward persistence is not such as to justify ignoring whatever help is in sight, even though its promise may be restricted in both genetic certainty and geographic applicability. We must, then, make the most of the general types of occurrence and relationship such as discussed above under the designation indices.

Approach may be made once again, through either statistical analysis or new observation.

(*a*) *Statistical.*—Assembly of all available data on features supposed to be associated with or indicative of the bottoming of ore bodies, with record of the frequence and relative abundance or accentuation of each factor, together with whatever of generalization and classification may be possible, both for all bottomed *ore shoots* and separately for all *districts* regarded or suspected to be *permanently*

[7] T. A. I. M. E. 144: 135, 1941.
[8] T. A. I. M. E. 144: 133–134, 1941.

bottomed. Perhaps the tabulation should be arranged also by major genetic types of deposits, since for widely different conditions of deposition different criteria may be significant.

(*b*) *Research.*—There is pressing need of many more descriptions, careful, explicit and objective, of conditions attending the bottoming of ore bodies and the fading out or exhaustion of mines and districts.[9] Especial care should be taken to keep clearly distinguished the observations which any competent group of observers would probably agree to be both factual and pertinent, those which are progressively less certain, and the inferences deduced from both sets of observations.

As later emphasized, studies of this kind can hope to yield only partial and superficial truth if they seek only simple, mechanistic explanations of why ore ceases downward.

9. *Causes of Downward Cessation of Ore.*—The assigned problem quite properly seeks the *causes* for ultimate failure of ore downward. The supposed indices or criteria of the bottoming of ore bodies are, for the most part, not themselves causes but the consequences of causes. Until or unless the fatal implication of one after another of these empirical features becomes statistically overwhelming, the geologist is obligated to seek the true causation behind these indices, themselves so often vague or mystifying. Even if the statistics do acquire such consistent pointing as to court acceptance, the empirical criteria either must be logically fitted into a rational concept of the ore-depositing process, or else they can hope to retain only a highly speculative and unreliable status. In short, the problem of downward persistence of hypogene ore is so complex and involved that, lacking as yet direct experimental means of linking cause and effect, *enlightenment must currently be sought chiefly from that great body of theoretical considerations of hypogene ore deposition which seem to be slowly establishing their approximate validity under accumulating tests.*[10]

10. *How Deal with these Causes?*—This seems like a staggering contract. *It is staggering.* Like the cause of cancer or the common cold, it will remain a live and pressing problem for a time too long to forecast. Yet piecemeal progress can be expected, as increments to the little already achieved. Fortunately the problem is not a hopeless tangle of unknowns completely devoid of the faintest glimmer of how or where to start thinking it out.

[9] Many companies, of course, are reluctant to permit publication on such matters. Occasionally there are proper grounds for temporary secrecy; but more commonly reticence is arbitrary and shortsighted—and often futile as well, for if the instance is one of importance, more or less distorted knowledge of it is almost sure to be abroad, for the worst possible use that may be made of it. The mining industry is gradually coming to realize that the art advances most rapidly under free scientific interchange. Geologists should promote appreciation of this fact; not least, those who are members of company staffs.

[10] Right here enters danger of a serious anomaly. The company geologists and those in private practice have the greatest stake and the greatest responsibility in ascertaining why ores quit downward; and they have, also, the best opportunity of knowing the facts and watching the significant changes brought to light by extending development. Yet unfortunately, as matters now stand—though there are conspicuous exceptions—they are the ones least likely to have faith in what are often called the "highbrow" considerations, or expertness in dealing adequately with them. This is a situation which must not and cannot continue. The growing difficulty of ore finding makes dependence on empiricism steadily the less effective, and ever deeper scientific understanding the more indispensable. This is the inevitable trend in geology, as it already so markedly is in every other applied science. Aspirants for entrance into the profession may well heed this trend.

To visualize hypogene ore occurring continuously or intermittently down to where ore ultimately ceases is to reverse the direction usually involved in its formation. Therefore, for *epigenetic* hypogene ores, thinking is likely to be facilitated by starting at the source—the magma—and following the ascending mineral-bearing solution and the varying conditions it encounters in rising[11] through ground in which it deposits nothing of commercial value into ground where it begins to deposit valuable mineral in quantity and grade requisite to constitute ore.

Wholly reasonable examples may be entertained in which extremely simple conditions would bring about the beginning of commercial ore deposition by the ascending solutions. For example, suppose the solutions being emanated from the source were obliged for the deeper long portion of their ascent to ooze through a most disperse "channelway" within which, even if mineral precipitation were going on, no sufficiently concentrated deposition could take place—only, at best, a hopelessly low grade stockwork, something like the 0.1 per cent Cu protore of a "porphyry copper." Eventually, however, the solutions, constantly seeking easy permeability, would reach a horizon where the fractures were sufficiently free and localized to permit the deposition of commercial ore. The under side of that horizon would mark the "downward limit" of hypogene ore deposition. Or, suppose the solutions as they leave the source, although possibly capable of depositing the abundant but worthless components, such as quartz, calcite or pyrite, were not yet sufficiently saturated with, say, copper or lead to precipitate those metals more than sporadically and stingily. But if the solutions should eventually pass into a highly reactive rock, say, limestone, reactions might go on which would precipitate the ore minerals in commercial proportion. The bottom of this reactive rock would be the "downward limit" for that occurrence. Just this situation may possibly serve to explain why so many limestone-replacement ore bodies seem to be without important feeders from below.

Although in our present state of understanding we cannot recognize the criteria which indicate that such simple examples as those cited represent the *deepest* ore formed along the given pathway of ascent, these instances do show that answers to the assigned problem can be visualized without dependence on any mystical hocuspocus. From such extreme simplicity, complexities may accumulate until an opposite extreme of baffling involvement is reached. Obviously, thinking and action should begin with the cases that seem to be least entangled.

Our problem, then, brings us face to face with the whole gamut of causes of hypogene ore deposition. Some workers will feel competent and be impelled to deal with the various structural influences that help to produce in the solutions supersaturation and precipitation. Others will wish to attack, either intellectually or experimentally, essentially physico-chemical aspects of the problem. Still others will be led to adopt certain intriguing cases encountered in the field as the springboard for their further examination and thought.

Only a few specific topics need to be mentioned as samples. Those competent

[11] For the much less common class of *syngenetic* hypogene deposits (which virtually means those formed by direct segregation from the molten magma and fixed within the crystallizing rock mass or at and immediately adjacent to its boundary contact), considerably different conditions and causes of metal concentration are likely to occasion downward or lateral migration of the ore-stuff.

and inspired to pursue such investigations will doubtless have their own ideas of objective and procedure.

On the structural side, the various aspects of permeability and of specific surface seem outstandingly important; above all, the permeability and specific surface existing at that stage in the total depositional process when the valuable minerals are being precipitated. In the physico-chemical area, a venerable challenge is the manner in which the mineral components are carried: gas, true solution or colloidal dispersion. To test true solubility, pure H_2O can no longer be realistically entertained; but the effect therein of ionic concentration of H, S, CO_3 at elevated temperature *and* pressure is crying for investigation. If the manner of transport can be cornered, the causes of deposition should be the more surely indicated. Among these latter may here be mentioned the old stand-bys, such as fall of temperature and of pressure, or change in the temperature-pressure balance, reaction with wall-rock, change in pH, boiling or condensation of solution.

IXa. Accurate Mapping, Great Basin.

S. G. LASKY.

The ranking of this subject as ninth in a list of 30 needing attention in the field of metalliferous geology, reflects three widely-held beliefs: one, that broad regional knowledge is necessary for full understanding of more local information; two, that accurate regional mapping should lead to generalizations, in addition to those already employed by geologists, that will help in recognizing potentially productive mining areas; and three, that greater detail in mapping is necessary.

Whereas it was once believed that the fundamental features of Great Basin geology were fairly well known, much uncertainty now exists, for it has been discovered that the Province has experienced a complicated orogenic history extending over a long time. There has been no concerted attack on Great Basin geology as such nor, except for physiography, on any specific problem. The nearest approach to such an attack is represented by the several chapters (by Wilson for Arizona, Nolan for Utah, Nevada, and California, and Lasky for New Mexico) on the Basin-and-Range Province in the volume on North America in "Geologie der Erde." The publication of this volume, by Gebruder Borntraeger, Berlin, was stopped by the advent of the war. Present-day studies are incidental to the economic work of Federal and State Surveys or consist of specific local investigations, like those of Longwell in the Muddy River region and those of Professor Kirk Bryan's students in New Mexico. Hewett and Noble are sponsoring a comprehensive study of the Mojave region.

Because of the magnitude and complexity of the task, accurate mapping of the entire Great Basin is not feasible as a special project for early completion. However, noteworthy results can be achieve if geologists working in the region are uniformly alert to the problem and if they integrate their knowledge and efforts. The following sub-problems are among the outstanding ones having a bearing on the metalliferous geology of the Province:

1. Limits of the Province.—Some major mining districts lie within an ill-defined transition zone between the Basin-and-Range and Plateau Prov-

inces, in areas of complicated old structure exposed by recession of the mid-Tertiary lavas of the Plateau.

2. General fault history, relation of thrust faulting to origin of the ranges, and dating of basin-and-range distribution.—At least seven major episodes of faulting are known. Among the thrust faults, some are as young as late Miocene, and many have controlled the construction and distribution of ranges. Graben development on a large scale began as early as Eocene time (pre-thrusting locally), but at least in part the general outline and distribution of the ranges as now known first took shape following the mid-Tertiary volcanism, the newly-formed basins lying within the limits of older ones.

3. Relation of stocks to structure, in both space and time.—(*a*) Some stocks in the Province are known to have gained entrance to their present habitat by way of pre-existing deep-cutting thrust, tear, or normal faults.

(*b*) Mechanics of stock emplacement. Forcible injection, stoping, assimilation, and igneous replacement are known to have been operative.

(*c*) Related deformation of enclosing rocks.

(*d*) Size and shape of stocks. Not many have orthdox shapes, getting larger with depth. Some are shaped like horse-shoe nails driven concordantly into the sediments; some are irregular blobs with dangling roots.

4. Stratigraphy of the Province and the relation of ore deposits to formations of various ages and characteristics.

5. Separation of Jurassic and Cretaceous volcanics from the mid-Tertiary volcanics. The older volcanics are host rocks for Laramide and later mineral deposits; the Tertiary volcanics constitute a cover for the Laramide deposits but a host rock for others.

6. Pedimentation. Several periods are known, the earliest associated with the Eocene grabens. The extent of present-day pediments, their relation to the faults supposedly bounding the ranges, and the thickness of the gravel deposits covering them are important factors in the search for concealed mineral deposits.

Most past regional mapping within the Province has been on a scale of 1:125,000 or smaller. The present tendency is to map smaller quadrangles (15-minute and 7½-minute) on larger scales. Some of the older mapped areas are being remapped in greater detail, on scales as large as 1:12,000. Most new topographic mapping by the U. S. Geological Survey will be by 7½-minute quadrangles.

During the past three years, Miss Leona Boardman of the Geological Survey has been compiling index maps of each State, showing the amount and kind of geologic mapping done. Master copies are kept posted as new geologic maps are published. Although none of the index maps for the States in the Great Basin are yet available for distribution, it is expected that eventually all will be published by the Federal Survey. In the meantime, inquiries about geologic map coverage can be directed to the Geological Survey in Washington.

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IXB. EMPLACEMENT OF IGNEOUS ROCKS IN RELATION TO FAVORABLE STRUCTURES.

CARLTON D. HULIN.

Geologists concerned with the origin of hydrothermal ore deposits have long approached the problem with the assumption that the deposit was genetically related to immediately adjacent portions of exposed igneous intrusives such as stocks and batholiths. While there can be no question about the close special relationship which exists between many ore deposits and intrusive igneous bodies, this spacial relationship cannot be held to imply derivation of the mineralization from the more immediately exposed portions of the igneous bodies.

More nebulous, but of even greater importance in its implications concerning the origin of such ore deposits, is the time relationship which exists between the mineralization and the attendant igneous intrusives. In all cases where the time relations can be established, and in all depth zones of mineralization, the formation of the ore deposit is found to be entirely later than the time of solidification of the exposed portion of the associated igneous body and separated therefrom by a distinct interval which is recorded in a variety of geologic events including fault history and changing physical conditions and frequently by the injection of highly specialized differentiation facies of the igneous magma.

The close correspondence in the historical sequence of events expressed in the several depth zones of mineralization strongly indicates that within any cycle of mineralization the similar events and changes recorded in the mineralization of the several depth zones must be concurrent and therefore mutually controlled by origin from a common source, a source which is so deeply buried as to be nowhere exposed to view.

Admittedly the exact timing of events during igneous invasion and attendant mineralization is not easy of evaluation. A crying need exists for more factual data, quantitative in character, such as the work of E. S. Larsen [1] on the Baja California batholith, or that of W. D. Johnston, Jr.,[2] at Grass Valley.

The close spacial relationship which exists between many ore deposits and exposed portions of igneous intrusives, if not controlled by direct genetic causes, must be regarded as due to structural control, forces set in operation by the emplacement of the intrusive body preparing the ground and furnishing the stage setting for the subsequent mineralization. Volume changes resulting from crystallization of the intrusive and from recrystallization of some portion of the surrounding rock body, and further volume changes resulting first from the heating of the rock body and followed subsequently by changes due to cooling of the rock body, are adequate to explain not only the initial preparation of the ground ahead of the mineralization, but are peculiarly adapted to

[1] Larsen, Esper S.: Time required for the crystallization of the Great Batholith of Southern and Lower California, Amer. Jour. Sci. 243-A: 399–416, 1945.

[2] Johnston, W. D., Jr.: The gold quartz veins of Grass Valley, California, U. S. Geol. Surv., Prof. Pap. 194, 1940.

explain the continual recurrence throughout the period of mineralization of minor fault movements so necessary for the maintenance of permeability in the rock body without which the mineralization would choke itself off. A static ore structure is important! To be favorable, an ore structure must be dynamically active, and in the volume changes occurring in the rock body there exists the mechanism responsible for dynamically active structures and maintenance of permeability. The factors involved have been treated in more detail elsewhere.[3]

If the mineralizing solutions are ascending from some deep underlying source rather than passing laterally outward from adjacent portions of the igneous intrusive, our ideas of the deposition of metals are currently expressed in the "Zonal Theory" are subject to radical revision. More information is needed on the effects of "lateral" as compared with "vertical" zoning.

If the close spacial relationship between ore deposits and intrusive igneous bodies is recognized as being controlled by structural and dynamic causes resulting from the emplacement of the intrusive, many questions arise for which no answers are available in the current literature on ore deposits.

What has controlled the locations chosen for emplacement of the stocks with which so many of our ore deposits are associated? Why are highly differentiated dike facies so regularly present within mineralized districts, though usually absent from surrounding and intervening areas? Why is the emplacement of certain stocks followed by intensive mineralization, whereas other stocks apparently of comparable character are barren of attendant ore deposits? Why indeed are the mineralizing solutions ever attendant upon any stock, rather than appearing at a location ten or twenty miles distant? Does some direct relationship of other than spacial character exist between certain stocks and the underlying source of the mineralizing solutions?

The answers to these and to many more detailed questions indeed demands more factual information than is now available. Increased knowledge is in particular needed concerning the physical characteristics of rock materials. Accurate data are needed on the stress reaction of rocks in the range of higher temperatures and pressures, and on the volume changes resulting from change of state. Only fragmentary information exists concerning the coefficients of thermal expansion in the range of higher temperatures and pressures, though it is known that the thermal coefficients differ for different rock materials. Limestone, for example, has a coefficient of thermal expansion which is somewhat greater than that of most rocks. Is this a factor in the common occurrence of ore bodies in limestone?

The problems are important and offer a challenge to all geologists who work with ore deposits. The season is wide open, there is no bag limit, and the hunting should be good.

[3] Hulin, Carlton D.: Factors in the localization of mineralized districts, A. I. M. E., Min. Tech., Jan. 1945.

X. Transportation and Deposition of Silica.

EARL INGERSON.

PRESENT STATE OF KNOWLEDGE.

Solubility of Silica.—A number of workers have determined the solubility of silica up to 300 or 350° C., and there are some determinations above the critical temperature of water. Morey and Ingerson (1937) have summarized the results to 1937. Later determinations are given by Morey and Ingerson (1941) and by Kennedy (1944). The results of the various workers are in general agreement and show that pure water can dissolve an appreciable amount of silica both below and above the critical temperature. For example, at 350° about 0.2 g. amorphous SiO_2 or silica glass dissolves in 100 g. of H_2O. For quartz the value is less, being between 0.1 and 0.15 parts per 100.

At relatively low pressures (< 300 atm.) solubility decreases as the critical temperature is approached and exceeded. If the pressure is sufficiently high, however, solubility increases continuously with increasing temperature.

The presence of CO_2 decreases the solubility considerably. For example, with pressure CO_2 equal to that of the water solubility of silica is decreased something like 50 per cent.

Experimental Production of Quartz.—Quartz has been formed in a large variety of experiments, anhydrous and hydrous, below and above the critical temperatures of the solutions concerned. Kerr and Armstrong (1943) have given a complete summary of these experiments.

Equilibrium Studies.—Quartz is a primary phase in many systems. Those of the type alkali oxide-silica-water are of particular interest in problems of transportation and deposition because it is probable that some compositions in these systems are analogous to solutions that have deposited quartz in nature. When alkalis are present much more silica can be held in solution under the same conditions of temperature and pressure than with pure water.

Morey and Fenner (1917) have made the most complete study of such a system thus far attempted (K_2SiO_3-H_2O-SiO_2). Parts of the system Na_2O-SiO_2-H_2O have been investigated by Morey and Burlew (1938) and by Morey and Ingerson (1938). Morey and Fleischer (1940) studied part of the system K_2O-SiO_2-CO_2-H_2O. Much of the work has centered around the parts of the systems where quartz is the primary phase, so the compositions, in these systems, from which quartz crystallizes most readily are fairly well known.

WORK IN PROGRESS.

Work is continuing on some of the systems mentioned above. Morey and Burlew, at the Geophysical Laboratory, are studying equilibrium relationships in the system Na_2O-Al_2O_3-SiO_2-H_2O. Bowen and Tuttle, at the Geophysical Laboratory, are studying the systems K_2O-Al_2O_3-SiO_2-H_2O and

K_2O-MgO-SiO_2-H_2O. Kennedy, at Harvard, is continuing his studies on solubility of silica and intends to cover the range up to 700° C. and 2,000 atm.

Growth of Large Quartz Crystals.—The Brush Development Company (Hans Jaffe) and Antioch College (A. C. Swinnerton) are investigating the growth of large quartz crystals under the sponsorship of the Signal Corps Engineering Laboratories, Ft. Monmouth, New Jersey. Both groups started with information on the methods used by Spezia and by Nacken. They have confirmed that silica can be transported and deposited as clear quartz both above and below the critical temperature of water. Kerr and Armstrong (1943) describe the work of Spezia. Nacken's work depends in part on the fact that quartz is less soluble than is amorphous silica. He used small quantities of $NaHCO_3$ or sodium abate, apparently to increase solubility and transport of silica and to inhibit the formation of new nuclei. Details of Nacken's work are given in a report by Swinnerton (1946).

The Bell Telephone Laboratories (A. C. Walker) are also using Nacken's method, and modifications thereof, in attempting to grow large quartz crystals. They have been bothered by the rapid conversion of amorphous silica to quartz *in situ* and are now working on a method of using crystalline quartz as nutrient material.

At the Naval Research Laboratory (I. I. Friedman) work is in progress on the system $Na_2Si_2O_5$-SiO_2-H_2O, with emphasis on the boundary between $Na_2Si_2O_5$ and quartz. The boundary of the quartz field has been determined at several temperatures by measuring "solubility" of quartz in solutions of NaOH. For this work quartz oscillator plates are used. In other experiments silica glass is used. Quartz is grown by saturating a solution at elevated temperature and allowing the system to cool slowly; the excess SiO_2 deposits readily as clear quartz on prepared quartz plates.

Studies of Natural Quartz Crystals.—From detailed studies of liquid inclusions in quartz crystals it is possible to get some information about the temperature, pressure, and concentration relations of the solutions from which the crystals grew. Ingerson (1947) has summarized the subject and suggested some improvements in technique and theory of interpretation. Work is continuing and several crystals with large liquid inclusions are available from which it should be possible to gain more information about the compositions of the solutions.

ADDITIONAL WORK NEEDED.

Natural Solutions.—Very little information is available on the character of solutions from which quartz has formed in nature. Attempts should be made to obtain and analyze as many samples of primary solutions as possible, not only from liquid inclusions in individual crystals, but also from vugs in quartz veins and from geodes.

Much more work should be done on probable pressure-temperature relationships by studying liquid inclusions from quartz selected for variety geographically as well as geologically.

Equilibrium studies should be continued and expanded. The systems on which work is being done at present will yield much information, but there

is at least one other on which work should be started in the near future—Na_2O-K_2O-SiO_2-H_2O. In the ternary system with soda retrograde solubility is encountered, but is not observed with potash. In the quatunary system, therefore, it may be possible to control solution and crystallization almost at will when the equilibrium relations are well enough known.

Crystal Growth.—Equilibrium studies yield a great deal of information about crystal growth, but other methods of attack are also worthwhile and can even give things of considerable importance that may not appear from the thorough investigation of a system.

For example, rates of solution and deposition should be studied, and the effects on these things of impurities such as CO_2, Cl^-, SO_4^-, Li^+, etc. (in systems containing Na_2O and/or K_2O). An investigation of twinning in artificial crystals should be made, as to how it is produced and how it can be avoided; also a similar study with respect to inclusions.

Similar experiments should be run with solutions as nearly identical to natural solutions as possible and the results compared with those obtained with the most favorable artificial mixtures yet studied, as to rate of growth, habit, twinning, inclusions, and nuclei per cm.^{2} per gram of material.

REFERENCES.

Ingerson, Earl (1947): Liquid inclusions in geologic thermometry, Am. Min., vol. 32, pp. 375–388.

Ingerson, Earl, and Morey, G. W. (1941): Solubility, transport, and crystallization by means of a vapor phase, Trans. Amer. Geoph. Union, p. 504.

Kennedy, George (1944): The hydrothermal solubility of silica, Econ. Geol. 39: 25–36.

Kerr, Paul F., and Armstrong, Elizabeth (1943): Recorded experiments in the production of quartz, Bull. Geol. Soc. Amer., vol. 54, Suppl. 1, pp. 1–34.

Morey, G. W., and Burley, J. S. (1938): Studies of solubility in systems containing alkali and water, Amer. Jour. Sci. 35A (5): 185–215.

Morey, G. W., and Fenner, C. N. (1917): The ternary system H_2O-K_2SiO_3-SiO_2, Jour. Amer. Chem. Soc. 39: 1173–1229.

Morey, G. W., and Fleischer, Michael (1940): Equilibrium between vapor and liquid phases in the system CO_2-H_2O-K_2O-SiO_2, Bull. Geol. Soc. Amer. 51: 1035–1057.

Morey, G. W., and Ingerson, Earl (1937): The pneumatolytic and hydrothermal alteration and synthesis of silicates, Econ. Geol., Suppl. to No. 5, pp. 607–761, Aug. 1937.

Morey, G. W., and Ingerson, Earl (1938): The system water-sodium disilicate, Amer. Jour. Sci. 35A: 217–229.

Swinnerton, A. C. (1946): Report of investigations in European Theater with special reference to the German ersatz quartz program and wartime crystal industry and the quartz developments and piezoelectric materials investigations in the United States, U. S. War Dept. Signal Corps Report P.B. 28897, 37 pp.

GEOLOGY AND GROUND-WATER RESOURCES OF PUERTO RICO.[1]

C. L. McGUINNESS.

ABSTRACT.

Puerto Rico, the easternmost and smallest of the Greater Antilles, has an axis of deformed and metamorphosed volcanic rocks of Upper Cretaceous age, intruded by dioritic rocks during the Antillean revolution. The hard-rock core is flanked on the north and south by limestones and clastic rocks of late Oligocene and early Miocene age, which have been gently arched and uplifted. Similar rocks were deposited in late Miocene or early Pliocene time along the west coast. During the Quaternary the island has been separated from the other major Antillean islands by faulting and has been arched, uplifted, and tilted to the northeast. Alluvium and littoral deposits have partially filled the valleys and have formed coastal plains on the north and south.

The Upper Cretaceous volcanic and associated rocks yield small supplies of water to wells in most places. The Tertiary limestones yield large supplies in some places on the north, south, and west coasts. The Quaternary sands and gravels are the most important aquifers. They yield about 200 million gallons a day to wells in the main south coastal plain alone. The water is used largely for irrigation. A total of perhaps 250 to 300 million gallons a day is pumped from wells in the island, and moderate to large additional supplies are available in some places.

A SYSTEMATIC areal investigation of the ground-water resources of Puerto Rico, involving about 5 months of field work by the writer, was made during the period September 1945–March 1946 by the Geological Survey in cooperation with the Puerto Rico Aqueduct and Sewer Service. The Aqueduct and Sewer Service was created in 1945 by an act of the Insular Legislature and is charged with the responsibility of providing adequate services of water supply and sanitary sewage disposal for the communities of the island. It is estimated that, at the time the Service was formed, not more than 10 per cent of the population of approximately 2,000,000 was served with an adequate supply of safe water. The ground-water investigation was made largely for the purpose of determining the availability of ground water for public supply in different parts of the island, but the information obtained of course can be used in the development of ground-water supplies for any purpose.

Puerto Rico is the easternmost and smallest of the Greater Antilles, the others of which are Cuba, Jamaica, and Haití or Hispaniola. The islands of Vieques and Culebra, east of and attached politically to Puerto Rico, and the Virgin Islands, though considered a part of the Lesser Antilles, are closely related to the Greater Antilles geologically and from that standpoint should be

[1] Presented March 20, 1947, at the New York Annual Meeting of Society of Economic Geologists. Published by permission of the Director, U. S. Geological Survey.

included with them. The islands of the Greater Antilles represent remnants of a large landmass that formerly extended from Cuba to the Virgin Islands and has been broken up by faulting. The downfaulted blocks form some of the greatest deeps of the Atlantic Ocean and Caribbean Sea. An excellent description of the geology and physiography of Puerto Rico is given by Meyerhoff.[2]

Puerto Rico, together with the other major islands of the Greater Antilles, is built largely of volcanic and intrusive rocks of Upper Cretaceous age. The volcanic rocks are of andesitic composition and consist largely of agglomerate, tuff, and ashy shale, but they include thick lava flows and numerous shallow intrusives. Those in Puerto Rico are believed to have been extruded mainly from two large volcanoes. Interbedded with the shales are a number of beds of limestone.

Following their deposition the volcanic rocks and limestones were folded by strong pressures from the south and southwest and were intruded by dioritic rocks, presumably derived from the same reservoir of magma that fed the volcanoes. The dioritic rocks appear to underlie the entire island and have been exposed by erosion in two large and many small areas. The silica-rich water vapor that escaped from the dioritic rocks when they cooled permeated the still-unconsolidated volcanic rocks and indurated them to a remarkably even degree, so that they are now largely hard and dense. The Cretaceous limestones have been partly recrystallized in many places.

The Cretaceous rocks are flanked on the north and south by clastic sediments and limestones whose deposition began in middle Oligocene time and extended through lower Miocene time. The deposits formed at first include clastic materials that grade laterally into earthy and then into pure reef-type limestones. The deposits also grade upward into pure reef-type limestones that form thick beds at the top of the north and south coast Tertiary sections.[3]

Tertiary deposition on the north and south coasts was ended in the latter part of the Miocene by earth pressures from the south that arched the newly formed coastal plains and raised them above sea level. The Tertiary rocks of the south coast were gently folded at this time. Fossils in cuttings in several wells penetrating limestone and clastic sediments in the Mayagüez Valley, on the west coast, appear to be of late Miocene or perhaps even early Pliocene age, suggesting that the west coast of the island may have sagged below sea level at the same time that the north and south coasts were uplifted.

According to the available evidence, deposition along the west coast was halted at or soon after the beginning of the Pliocene by a vertical uplift of about 800 feet, and during the rest of the Pliocene the island underwent erosion. During the Pleistocene the Antillean landmass was broken up by faulting, and the block comprising Puerto Rico and the northern Virgin Islands was arched and tilted toward the northeast. This resulted in uplift of the western part of the island and in drowning of the valleys in the east, so that

[2] Meyerhoff, H. A., The geology of Puerto Rico. Univ. Puerto Rico Mon., ser. B, no. 1, 1933.

[3] Thomas, C. R., Bergquist, H. R., and Zapp, A. D., Oil possibilities of Puerto Rico. U. S. Geol. Survey typewritten report, 1945.

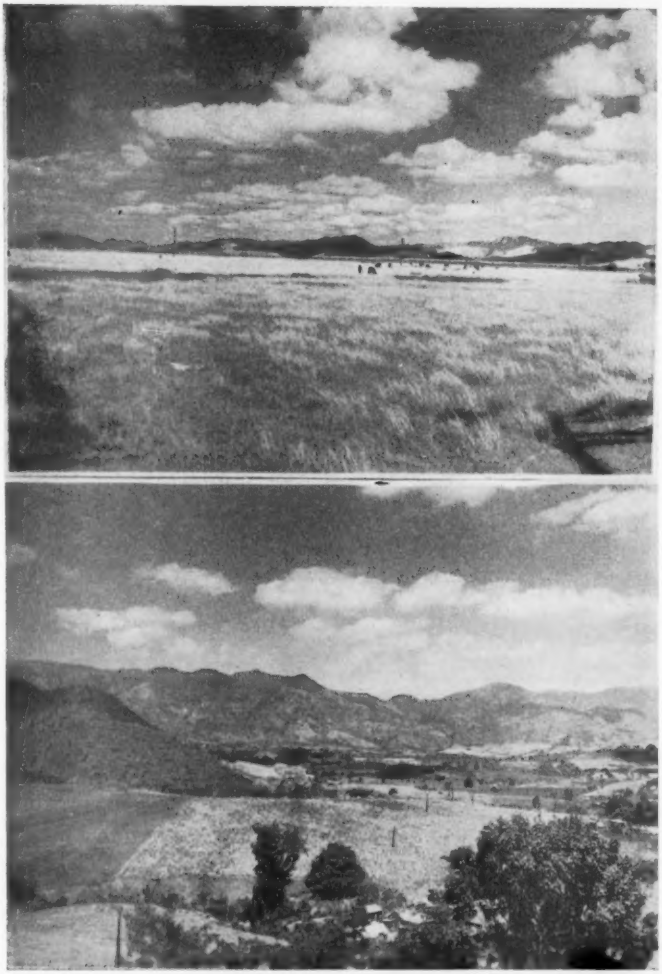

FIG. 1 (upper). Part of main south coastal plain, looking northwest from a point between Guayama and Salinas, near the eastern end of the plain.

FIG. 2 (lower). Cordillera Central, looking north from a point north of Juana Díaz, about at the middle of the south side of the island.

Culebra, Vieques, and the northern Virgin Islands became separated from Puerto Rico. St. Croix is separated from both Puerto Rico and the northern Virgin Islands by a deeply downfaulted block. Puerto Rico is separated from the island of Haití to the west by the downfaulted blocks that underlie Mona Passage.

More or less vigorous earth movements have continued to the present time, and these and the oscillations of sea level associated with Pleistocene glaciation have complicated the erosional and depositional processes in the island. However, extensive deposits of gravel, sand, and clay have been laid down in the valleys and around the edges of the island, especially along the south coast, where a plain 3 to 4 miles wide occupies a largely uninterrupted strip more than 40 miles long (Fig. 1).

The island itself is small. It is nearly rectangular, with a length of a little more than 100 miles, an average width of about 35 miles, and an area of about 3,400 square miles. The maximum altitude is a little less than 4,400 feet. The climate is tropical marine and the average rainfall is 70 inches, about the same as the average for the landmasses of the entire Caribbean region. The rainfall ranges from more than 200 inches on the highest peaks of the Sierra de Luquillo at the east end of the island, where the moisture-laden trade winds drop a substantial part of their water, to 25 or 30 inches at the southwest corner, where the high and equable temperature and great evaporativity produce conditions similar to those in areas in the western United States with less than half as much rainfall.

The island is quite rugged. The maximum altitudes are not great, but the mountains are more impressive than they would be on a larger island (Fig. 2).

As water-bearers the rocks of the island fall conveniently into three classes: The Upper Cretaceous igneous rocks and subordinate crystalline limestones, the Tertiary limestones and subordinate clastic rocks, and the Quaternary alluvium and littoral deposits.

The Cretaceous rocks yield water only from fractures and weathered zones, except for the limestones, which yield water from solution channels. The igneous rocks yield from almost nothing to a few hundred gallons a minute per well, depending on the extent of fracturing and weathering and the conditions of recharge, and the average yield for a large number of wells might be 10 or 15 gallons a minute. Where pure the Cretaceous limestones are fairly good water-bearers, but the total area of outcrop is small. For domestic wells and public-supply wells for small communities the Cretaceous rocks offer considerable promise.

Figure 3 shows some of the folded and jointed indurated shale that forms one of the best water-bearers among the Cretaceous rocks where the conditions of recharge are good. Figure 4 shows an exposure of the crystalline limestone of Cretaceous age, which is extensively used for road metal. Figure 5 shows a weathered exposure of indurated Cretaceous agglomerate or conglomerate. The agglomerates are only fair water-bearers.

The Tertiary rocks range from poor to excellent as aquifers. The poorest are the clays, shales, and earthy limestones laid down during the early stages

FIG. 3 (upper). Weathered exposure of folded, faulted, and jointed indurated shale of Cretaceous age, about 10 miles northwest of Ponce.

FIG. 4 (lower). Crystalline blue limestone of Cretaceous age, about 10 miles south of San Juan.

FIG. 5 (upper). Weathered exposure of indurated Cretaceous agglomerate or conglomerate near Coamo.

FIG. 6 (lower). Earthy limestone of Tertiary age about 5 miles southwest of San Juan, showing small normal fault.

FIG. 7 (upper). Cliffs of pure reef-type limestone of Tertiary age about 7 miles south of Manatí.

FIG. 8 (lower). Roof of cavern in pure Tertiary limestone about 11 miles southwest of Arecibo.

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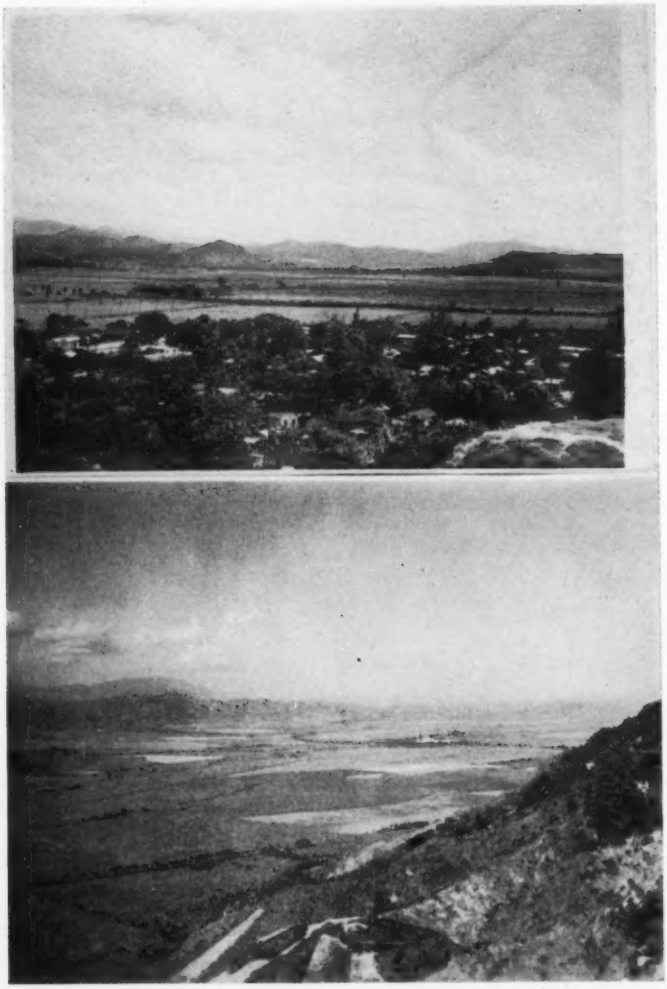

FIG. 9 (upper). Heavily pumped south-coast valley east of Ponce, at the west end of the main south coastal plain.

FIG. 10 (lower). Looking northeast across the Yabucoa Valley, typical of several valleys on the east coast that contain moderately thick and permeable deposits of water-bearing alluvium.

of deposition (Fig. 6). The best are the pure reef-type limestones in the areas where the conditions of recharge from rainfall or stream flow are good (Figs. 7 and 8). The most productive wells of the island are in the pure Tertiary limestones of the north and south coasts. Some of the individual wells could yield 10,000 or 20,000 gallons a minute, although the largest pumps that have been installed have capacities of 3,000 or 4,000 gallons a minute. However, some of the most productive areas are near the coast where the limestones yield salty water or will do so if wells are pumped too heavily.

The most important aquifers in the island, so far at least, are the Quaternary sands and gravels. Individual wells yielding several thousand gallons a minute have been drilled in many places, especially in the main south coastal plain. There a total of about 200 million gallons a day is pumped from wells, most of them penetrating alluvium, mainly for irrigation of sugar cane (Fig. 9). Considering the size of the main plain, roughly 150 square miles, this is a very large quantity of water. Irrigation with both ground and surface water is an important and perhaps a major source of recharge. The south coast is comparatively dry, and in the absence of irrigation the available ground-water supply would be much smaller. The alluvial deposits in a number of separated valleys on the southwest, west, and east coasts are important actual or potential sources of ground water (Fig. 10).

The ground waters of the island are generally hard, as would be expected from the predominance of rocks containing much calcium and magnesium. Except in the driest areas, however, they are only moderately mineralized. The dioritic rocks yield the softest and least mineralized water, in areas where the conditions of recharge are good.

A total of perhaps 250 to 300 million gallons a day is pumped from wells in the island as a whole. About 200 to 250 million gallons a day is pumped for irrigation, mostly for sugar cane. About 15 or 20 million gallons a day is pumped for industrial uses. About 7 or 8 million gallons a day is now pumped for public supply, but this quantity will soon be increasing rapidly. Finally, several million gallons a day is pumped for domestic and stock uses in rural areas. The ground-water supply of the south coastal area appears to be rather fully developed, but large additional supplies are available in some other parts of the island. A very great development of small-capacity wells for domestic uses and public supply is feasible and would go far in improving the health and comfort of the people of Puerto Rico.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
June 1, 1947.

THE ZINC CONTENT OF PLANTS ON THE FRIEDENSVILLE ZINC SLIME PONDS IN RELATION TO BIOGEOCHEMICAL PROSPECTING.*

W. O. ROBINSON, H. W. LAKIN, AND LAURA E. REICHEN.

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ABSTRACT.

The zinc content of thirty different kinds of plants growing on slime ponds containing on the average 12.5 per cent zinc were determined by the dithizone method. The zinc content ranged from 39 p.p.m. in the fruit of the false solomon's seal (*Smilacina racemosa*) to 5,400 in the horsetail (*Equisetum arvense*). This latter plant varied considerably in zinc at different places on the slime ponds. The zinc contents of the aspen (*Populus grandidentata*), ragweed (*Ambrosia artemisiifolia*), and horsetail grown on normal soils are compared to those on the slime ponds and it is recommended that the poplar and ragweed be studied further as indicators of zinc ore bodies.

INTRODUCTION.

THE use of indicator plants in prospecting for minerals and metals is probable as old as history. Mellor (11) [1] records that as early as 1460 John di Castro used the presence of old world holly in prospecting for alum. Singewald (15) tells us that in 1810 Isaac Tyson, Jr. was led to the discovery of chromium ores in Maryland and Pennsylvania "by his prompt recognition of the comparative barrenness of the vegetation of the serpentine terrain." Incidentally one of the characteristic features of these serpentine barrens is the presence of scrub black jack oak.

The present investigation, sponsored by the Geological Survey, U. S. Department of the Interior, is part of a program of research and development on methods of prospecting for mineral deposits by tracing the distribution of ore metals in soil, vegetation, and natural water. The work at Friedensville was conducted jointly with the Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Department of Agriculture, and was materially helped by the cooperative attitude of the New Jersey Zinc Company on whose property many of the field data were collected.

* Published by permission of the Chief, Bureau of Plant Industry, Soils, and Agricultural Engineering, and the Director, U. S. Geological Survey.

[1] Figures in parentheses refer to Bibliography at end of paper.

It is commonly known that the character of the forest growth is a good indication of the agricultural value of a soil (see Hilgard 6). This means, in reality, that the kind and growth of the trees and plants are an indication of the chemical composition of the soil, modified, of course, by physical characteristics and atmospheric environment. A homely illustration of this may be given. In the early pioneer days of the covered wagon a family was moving westward over what is now Kentucky in search of a good farm. The oldest boy was getting tired of the monotonous journey and said, "Pop, we've gone far enough, this is good land and I want to settle here." "Alright," said his father, "just drive the team down along the river and hitch it to a paw-paw." After a bit the boy came back and reported he couldn't find a paw-paw. "Very well," said the father, "we'll drive on till we do find a paw-paw because the best river bottom land always grows paw-paws."

INDICATOR PLANTS.

Von Paul Dorn (5) claims that the calamine violet, *Viola calaminaria* Lej, is restricted to soils containing oxidized zinc ores. He also refers to *Thlaspi calaminaria* Lej et Court as showing a close relationship between its occurrence and underlying zinc deposits. This flower is said to be known among miners as "erzblume." Dorn rather enthusiastically describes plants that are used in prospecting for zinc, lead, tin and gold but gives little supporting evidence. He quotes O. Stutzer, no reference given, that *Amorphia canascens* Nutt. is an indicator of rich lead ores. It may be significant that in Gray's manual of Botany this plant is known as "lead plant." Brenchley (2), quoting work by Risse (1865), states that *Viola tricolor* and *Thlaspi alpestre* var. *calaminaria* are most characteristic on a soil of high zinc content, both showing such constant habit changes that they resemble new species. She reports 0.110 per cent zinc oxide (880 p.p.m. zinc) in the air dried leaves of *V. tricolor* and 1.500 per cent zinc oxide (12,000 p.p.m. zinc) in the leaves of *T. alpestre*. The latter value is higher than any we have obtained.

Vogt (16) considers that the analysis of plants for copper and zinc is of little use in prospecting. His experience is based mainly on the determination of copper and zinc in some plants growing over an exposure of copper ore of a mine in Norway. His analyses do not show significant changes in copper content of plants growing on and off the vicinity of the surface ore. However, there are marked and significant differences in the zinc content of the plants analyzed. The ore, here, is mainly copper with but little zinc.

McHargue and Roy (9) found that certain tree leaves contained from 3 to 39 p.p.m. copper but the variation in the zinc content of these leaves was very much greater, *i.e.* from 3 to 240 p.p.m. They determined the zinc and copper in the ash after burning at a low temperature. This ashing procedure has been criticized, for zinc may be lost due to volatilization of the reduced metal. Careful ignition reduces this loss to a minimum and it is doubtful if the above figures are much if any in error from this source. The data of Holmes (7) and other unpublished data in this laboratory show that the copper in plants where there is no "salting" due to dust contamination,

spraying, etc., will seldom be below 5 p.p.m. or above 15 p.p.m. The variation in the zinc content of a wide variety of plants is between a minimum of about 20 p.p.m. to a maximum of 10,200 p.p.m. Thus, it would seem that one cannot expect much indication of high copper in the soil from plant analyses for copper. From this viewpoint, however, the case for zinc is more promising.

One of the clearest cases of the mere presence of a plant indicating an unusual constituent of soil is that of the *Astragalus bisulcatus* indicating the presence of available selenium in the soil. This plant may accumulate as much as one per cent or more selenium and the mere presence of colonies of this plant is a fairly reliable indication of selenium in the soil (Byers et al. 3).

The *Astragalus bisulcatus* is both an indicator and an accumulator plant with respect to selenium. The part above ground of this plant may contain as much as 1.49 per cent selenium, dry weight basis (Beath 1). It is quite conceivable that a plant may contain no detectable quantity of a certain element and yet be an infallible indicator of the presence of this certain element in considerable quantities in the soil, for the reason that the presence of this element brings about certain conditions in the soil necessary for the growth of the plant. These conditions may be change of pH, presence or absence of accompanying elements, or the creation of a condition toxic to other plants so that natural competition is destroyed. A plant may appear to be an indicator plant due entirely to circumstantial evidence. Suppose a number of ore pits are opened in the same general locality at the same time and dumps are made exposed to plant growth. The plant having the best viable seed distribution and able to grow on such raw subsoil first might appear to be an indicator plant for that particular element being mined, whereas under natural conditions of surface soil competition it would have no value at all.

An ideal indicator plant is one that grows only on soils directly over ore deposits. It may, or may not, have any of the characteristic element in its tissues. An ideal accumulator plant is one that is widely distributed, the tissues of which contain the characteristic element proportional to the amount in the soil, and in quantities easily determined analytically. These terms, indicator and accumulator plants, are generally restricted to the minor elements.

Several years ago a number of common plants were collected and analyzed for zinc and copper. Holmes (7) reports some of them. L. T. Alexander collected ragweed, grapevine leaves, and white oak leaves in the vicinity of Zinc, Arkansas. On the side of an eroded valley exposing a weathered outcrop of oxidized zinc minerals he collected ragweed which contained 3,800 parts per million of zinc or 0.38 per cent, dry weight basis. On the soil formed from this outcrop, ragweed grew luxuriantly but other vegetation did not grow well. The leaves of the grape and oak did not contain much zinc. An old inhabitant told Alexander that where you found ragweed growing luxuriantly and other vegetation stunted in this region it was a good indication of a zinc mineral outcrop.

Quite recently Lakin has shown that ragweed growing on the semilateritic soils of nearby Maryland and Virginia such as the Dividson, Cecil,

and Chester soils will contain 20–50 p.p.m. zinc. In contrast to these soils, the Conowingo soils which are derived from serpentine grow ragweed containing 200 or more p.p.m. zinc.

TESTS ON FRIEDENSVILLE, PA., AREA.

Through the courtesy of the New Jersey Zinc Company opportunity was afforded for collecting plant growth and soils from two slime or tailing ponds adjacent to the Ueberoth and Old Hartman mines at Friedensville, Pa. The soil materials of these ponds are the fine-grained tailings accumulated in treating the oxidized zinc ores which these mines produced prior to 1890.

Physically the soil material of the slime ponds resembles the residual clay soils derived from the dolomitic limestones of the district. During the fifty or more years since deposition the material has been exposed to weathering and the ordinary soil forming processes. This is most clearly seen on some areas of the Old Hartman slime pond where there are surface layers one or two inches thick of black organic matter and a partial development of an A horizon of a normal soil section. Both ponds are for the most part well covered with normal-appearing weeds and grasses and in places there are a few shrubs and trees. Corn is grown on the margins, and, except for a few rows near a bare, wind blown space, appears to be of normal growth. The sediment is from 8 to 12 feet thick and averages 12.5 per cent zinc according to the analyses kindly given us by the New Jersey Zinc Company.

TABLE 1.

COMPOSITION OF COMPOSITE SAMPLE OF SLIME POND MATERIAL, UEBEROTH MINE.

SiO_2	51.4%	Cd	.01 %
Al_2O_3	13.8	Cu	.004
Fe_2O_3	8.3	Mn	.10
CaO	1.5	S total	.01
MgO	2.1	CO_2	1.9
Zn	12.5	Acid insol.	61.2
Pb	.01 (under)		

Analyses given by the New Jersey Zinc Company.

Table 1 shows the chemical composition of the slime pond material. Some small part of dolomite, probably less than three per cent, remains in the slimes. This figure is the dolomite equivalent of the carbon dioxide present and it is not improbable that some part of this carbon dioxide is present as zinc carbonate. The pH of the surface slimes, locally ranging between 7.8 and 8.1, indicates the presence of dolomite or calcite. In this respect it differs radically from the surface reaction of limestone residual soils which are normally acid on the surface. In following the soil and plant relations it is important that this alkaline reaction of the surface layer be kept in mind.

At the time it appeared to us that this was a splendid opportunity to find the maximum quantities of zinc a number of plants would take up; to find differences in the capacity of different kinds of plants to take up zinc; to

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find if there were unusual plants growing there, the mere presence of which could be taken to show the presence of high zinc soils; and finally to see if high zinc in the soil produced characteristic leaf colors or abnormalities of growth that could be useful in prospecting for zinc.

Plant and some soil samples were taken September 8 and 9, 1946. Enough plants were taken over a considerable area when possible to make a good average sample. Except as noted in Table 2 the analyzed specimens represent the whole plant above ground, except that the stems were cut far enough above ground to lessen the obvious soil contamination. The plants were identified in case of doubt by J. F. Hermann, of the Bureau of Plant Industry, and the scientific names are those he has assigned.

When gathering the plants it was obvious that some were contaminated with soil. This was especially true of the violet leaves. With these and a few of the other samples an attempt was made to brush the soil from the leaves and stems. While a considerable part of the attached soil could be removed by brushing, some very small quantity remained on the leaves. The plants were air dried in paper bags. In the drying process some soil particles dropped to the bottom of the bags and were removed whenever possible. On ordinary soils the zinc introduced by soil contamination is of little consequence but with a soil containing 12.5 per cent zinc it is an entirely different matter.

The plant samples were ground in a Wiley Mill and analyzed for zinc by the dithizone method described by Holmes (8). The results of the analyses are given in Table 2.

The most notable feature of Table 2 is that all the plants are tremendously high in zinc. The corn leaves, both specimens of which grew on the margins of the slime ponds, were apparently free from soil contamination, and they were about shoulder high. Those on the Ueberoth Mine area were a considerable distance from the slime deposits but undoubtedly received considerable wash from them. The corn leaves on the Old Hartman Mine area were directly on the edge of the slimes and on this area some of the corn planted had failed to come up. On ordinary agricultural soils similar corn leaves have 20–50 p.p.m. zinc.

The tree leaves with the exception of the poplar are lower in zinc than the low-growing plants. Some of the trees were on or just outside the margins. The sumac, sassafras, and hackberry were directly on the slime soil. All the tree leaves seemed to be quite free from soil contamination. The poplar leaves were growing on a rock dump containing some oxidizing sulphide ore, the leachings of which are very acid in reaction. These leaves were apparently free from soil contamination and the poplar seems to merit further investigation.

The butter and eggs and *Lobelia inflata* were not common inhabitants of the area, and, notwithstanding the fact that both are very high in zinc, did not seem to merit further study. The violet is so low-growing that it is visibly contaminated by soil in bare spots, and this contamination cannot be removed practically. Later, however, violets were found growing on grass sod in the slime area with a liberal accumulation of organic matter to protect

TABLE 2.

ZINC IN VEGETATION ON UEBEROTH SLIME POND, FRIEDENSVILLE, PENNA., COLLECTED SEPT. 8, 1946.

	Zn P.p.m. Dry Weight
Apple tree leaves, large tree on margin	180
Asparagus officinalis, large plant in full maturity	555
Butter and eggs, *Linaria vulgaris*	4,500
Cherry, *Prunus serotina* leaves, wild, black, near corn above	190
Clover, red, good growth including seeded tops	1,300
Corn, *Zea mays*, 4th leaf from tassel, beyond margin but received wash and erosion from slimes	270
Euphorbia maculata	660
Golden rod, *Solidago* sp.	600
Horsetail, *Equisetum arvense*	4,500
Lobelia inflata	4,400
Lobelia syphillitica, vigorous growth	620
Plantain, narrow leaved, *Plantago lanciolata*	540
Poplar leaves, *Populus grandidentata*	1,800
Pycnanthemum flexuosa Walt B.S.P.	900
Ragweed, *Ambrosia artemisiifolia*, composite sample from the area	1,800
Sassafras variifolium leaves	240
Shad bush, *Amelanchier canadensis* leaves	210
Solomon seal, false *Smilacina racemosa*, entire plant minus fruit	870
Fruit of above	39
Sumac, *Rhus typhina* leaves	330
Tomanthera auriculata (Michx.) Raf.	840
Tomanthera auriculata gathered about 2 weeks later	670
Violet, *Viola sagittata* (soil contamination)	3,500
Wild carrot, *Daucus carota;* Queen Anne's Lace	400
Yarrow, *Achillea Millefolium* L.	4,100
ON OLD HARTMAN SLIME POND.	
Corn leaves, 4th leaf below tassel, on edge of slimes	790
Ground cherry, *Physalis*, good growth	1,600
Hackberry, *Celtis occidentalis* var. *crassifolia* leaves	370
Fruit of above	106
Horsetail	4,900
Ragweed, *Ambrosia artemisiifolia*	3,400
Smart weed, *Persicaria Hydropiper*	1,300

them from actual soil particles. In certain bare spots where the surface soil had been recently removed, this violet was the first inhabitant.

The most common inhabitant was ragweed, and in view of previous knowledge, we expected this plant to be higher in zinc than we found it here. This soil, however, is alkaline in reaction, pH 7.9–8.1, whereas surface soils in humid regions are normally acid and it is common experience that nut and fruit trees are not able to take up much zinc from alkaline soils (alkaline from $CaCO_3$). The ragweed varied greatly in size on different locations on the slime ponds. It and the violet seemed to be the first plants that claimed the bare spots.

On both slime areas the horsetail was very high or highest in zinc. Vogt (16) has reported high zinc in horsetail. According to Němec (12) this plant also takes up considerable gold in certain areas. Further study of the horsetail and other plants high in zinc seemed desirable.

Two questions, in particular, needed to be answered. What was the variation in zinc content of the same plant on these slime areas, and to what

TABLE 3.

ZINC CONTENT OF PLANTS COLLECTED ON FRIEDENSVILLE SLIME PONDS, OCT. 8 AND 9, 1946.

Old Hartman Slime Pond.

Location		Zinc P.p.m. Dry Weight
1	Ragweed on ridge where corn failed to grow, tall	1,000
1	Ragweed, duplicate sampling of above	1,000
1	Ragweed in hollow between ridges, short	2,600
1	Ragweed, duplicate of above	1,800
2	Horsetail taken on north and south line	7,000
2	Horsetail, row parallel to above	5,800
2	Horsetail, row at right angles to above, meticulously brushed	3,200
2	Horsetail, row parallel to above, washed with water	1,900
3	Horsetail, scant new growth, now visibly contaminated	1,500
4	Yarrow, bottom leaves, on grass sod	660
4	Yarrow, tops on grass sod	470
5	Grass, good sod, accumulation of black organic matter	710
6	Violets on good soil, accumulation of black organic matter	1,200
6	Violets, duplicate of above	1,400
7	Horsetail, north and south line	1,700
7	Horsetail, duplicate to above, parallel line	3,400
7	Horsetail, east and west line	3,900
7	Horsetail, duplicate to above parallel line	3,100
8	Ragweed, larger plants	1,300
8	Ragweed, smaller plants	1,400
	Ueberoth Slime Pond.	
9	Poplar leaves, *Populus grandidentata*, taken September 8	1,800
9	Poplar bark of lower trunk	420
9	Poplar wood of lower trunk	60
9	Poplar bark of upper trunk	380
9	Poplar wood of upper trunk	51
10	Horsetail, new growth	5,400
10	Horsetail, duplicate of above	4,700
10	Violet in grass sod	1,300
11	Horsetail, new growth	2,500
11	Horsetail, duplicate of above	3,500
12	Horsetail, new growth	4,900
12	Red clover	640
12	Red clover, duplicate	460
13	Ragweed	2,400
13	Ragweed, duplicate of above	2,300
13	Poplar leaves, *Populus grandidentata*	1,400
14	Ragweed	1,300
14	Ragweed, duplicate of above	1,300
15	Poplar leaves, *Populus grandidentata*	2,000
15	Ferns, on rock pile	680
	In Vicinity, but not on Slime Ponds.	
19	Ragweed, north of 17	550
19	Ragweed, same general locality, sparse population	240
19	*Lobelia inflata*, few specimens	340
	Samples Taken at Distance from Zinc Deposits.	
	Poplar leaves, *P. grandidentata*, Hillendale, Md.	310
	Poplar leaves, *P. grandidentata*, Hillendale, Md., duplicate	310
	Poplar leaves, *P. grandidentata*, Ash Grove, Va.	150
	Shad bush leaves, Falls Church, Va.	24
	Horsetail, Falls Church, Va., near roadside	110
	Horsetail, Kenwood Beach, Va.	52
	Sassafras leaves, Falls Church, Va.	37
	Ragweed, Falls Church, Va.	128

extent did soil contamination affect the results of Table 2 and how could it be avoided? Another collection was made on Oct. 8 and 9, 1946. The zinc content of the plants collected is given in Table 3 together with that of the same kind of plants from other localities for comparison.

In the month that intervened between the two collections, the summer growth of horsetail had died and withered except the growth on location 2. The horsetail on this location may have been a later growth or had escaped the light frosts. It was green and succulent when sampled, and about the usual height of the mature specimens of the first collection. On all the other locations the horsetail was obviously of a new and immature growth, bright green, short and succulent. A minimum of 12 plants were collected for each sample.

The first two samples of horsetail on location 2 were not brushed or treated in any way, but in taking the samples the stems were cut at least 3 inches from the ground, and any plant having soil contamination visible to the unassisted eye was rejected. There is not a good duplication of the first two samples and the first sample is higher in zinc than any other sample taken from the slime ponds. The last two samples taken from location 2 are considerably lower in zinc than the first two. Very little suspended matter could be detected in the pail of water in which the last sample was washed. There is a possibility that some considerable zinc may have been washed out by the water. Church (4) states that nearly all of the large quantity of aluminum in the club mosses can be extracted with water. Some experiments made later on an air-dried and ground horsetail show that very little zinc is extracted by water. This does not necessarily mean that zinc is not extracted from the fresh sample. Samples of horsetail from the same site do not show good duplication and there is considerable range in zinc content of this plant over the two slime ponds. Some of this lack of duplication may be due to soil contamination, but it is felt that the most probable reason is great variability in the amount of zinc assimilated by different individuals of this plant even on this soil all samples of which are practically uniformly high in zinc. Horsetail from Falls Church and Kenwood Beach show low values of zinc indicating that this plant does not accumulate zinc on normal soils.

The tall ragweeds on location 1 had probably been stimulated in growth by the fertilizer applied in the row to the corn. It is conceivable that the phosphate of the fertilizer may have decreased the absorption of zinc. The short ragweed plants may also have had more soil contamination as it is more difficult to remove the soil particles from the smaller plant by brushing. Duplicate samples of the ragweed on sites 8, 13, and 14 show a good agreement, but there is a wide range in the zinc content of ragweed from different sites. There appeared to be some difference in the maturity of the plants, a factor which may affect the zinc content. The pH of the surface soil at the various locations over the slime ponds ranges between 7.5 and 8.1, most of the locations having the higher value. We would expect that these relatively small variations in pH would cause little or no variation in the zinc absorbed by plants from a soil having so much zinc, particularly as the values

are all above the neutral point. It has been suggested, however, that the root tips, by reason of the carbon dioxide they give off and possibly other acid root excreta may be in contact with a small zone of soil considerably more acid than the integrated soil mass sampled. Since the comparatively small quantity of carbonate particles, which would buffer the soil at pH 8.2, would be neutralized by a small quantity of acid, there may be considerable differences in pH of the root feeding zones at the various locations.

There is a very wide discrepancy between the zinc contents of the yarrow of location 4 on the Old Hartman slime pond and that gathered earlier on the Ueberoth slime pond. On location 4 there is very little chance of soil contamination, for here there is a grass sod and a good accumulation of organic matter. There was bare soil near where the first sample was gathered and no separation of the leaves and stems was made. There is not much difference in the zinc content of the leaves and the stems and tops of the second sample. It is probable that in the absence of any soil contamination the leaves would be higher in zinc than the stems and fruiting tops as is shown by the false solomon seal and hackberry samples in Table 2. The yarrow leaves are low on the ground and on account of their physical characteristics ordinarily would be prone to soil contamination.

There is rather good agreement of the zinc in the violet leaves taken at different sites of the later sampling and it would seem that there is little soil contamination even of low-growing species on grass sod where organic matter had accumulated as it had at the sites of the second sampling.

The poplar leaves of locations 9, 13, and 15 are from small trees on steep rocky slopes just above the margin of the slime ponds. There were numerous rock fragments containing acid oxidizing sulphide ores in the vicinity and the poplar tree roots may well be in contact with acid zones, thereby differing considerably from the plants growing on the slime ponds.

There were no poplar trees growing on the slime ponds for comparison of zinc contents. Poplar leaves seem to take up considerable zinc from soils of low zinc content as shown by the 310 and 150 p.p.m. on a kind of soil that would be expected to contain about 20 p.p.m. zinc. However, there is a great increase in zinc content of poplar leaves growing on the zinc ore locations. The poplar tree is widely distributed in the limestone valleys east of the Mississippi. The roots of the poplar penetrate deeper into the soil than ragweed, for instance, and it is far more widely distributed than the horsetail. From the few results available it would seem that poplar tree leaves offer the best possibilities of biogeochemical prospecting for zinc of any of the plants studied.

We were unable to find hickories growing on or very near the slime ponds. From other work it has been found that the leaves of hickory trees vary considerably in zinc content, ranging from 20 to 310 p.p.m. The soil that produced highest content of zinc in the hickory leaves did not contain an abnormally large quantity of zinc in the layers down to 30 inches deep. Hickory trees have a taproot and penetrate deeply into the ground and have a wide distribution. Hickory leaves have been found to take up unusually large quantities of rare earths (Robinson and Edgington 13) and boron (McHargue et al. 9; Robinson and Edgington 14).

It appeared that the false solomon's seal and hackberry on the slime ponds were more heavily fruited than normal and to one of us the corn leaves presented an unusual appearance. This "fancied" appearance was not confirmed by the other observers. Aside from these very minor observations there was nothing unusual in the appearance of the plants to indicate their very high content of zinc; with the exception that witches' broom is very prevalent in the hackberry.

As to the mere presence of a plant indicating the presence of soils high in zinc, there is only one very remote possibility. That is the *Tomantheria auriculata*. It is reported only in the general area of the zinc deposits in eastern Pennsylvania and Missouri. This plant is rare. On the slime ponds there is an unusual soil condition in that the surface soil has a pH above 7 and contains much zinc, whereas normally uncultivated surface soils are acid. Further investigation is needed here.

The quantities of zinc found in the plants on the slime ponds are far from a maximum. A sample of purslane collected on the acid Zn-bearing peats at Manning, N. Y., by Mrs. Helen Cannon contained over one per cent zinc or over 10,000 p.p.m.

The form in which zinc occurs in plants naturally excites curiosity. The quantity found has been shown to be widely variable. Carbonic anhydrase has been reported in plants. This is an enzyme connected with respiration. Zinc forms but three-tenths of one per cent of the enzyme so the zinc in this form would account for only a very small part of the total zinc in the high zinc plants. It is remarkable that such large quantities of zinc as those reported in this paper are not toxic. Wilstatter and Stoll (17) describe derivatives of chlorophyll in which magnesium is replaced by zinc. If such a compound were present in plants, it would still account for only a part of the zinc present in plants having the larger zinc content.

From a consideration of the data presented it would seem that indications of probable zinc deposits in the limestone residual soils may be revealed by the analyses of poplar leaves on the wooded and uncultivated areas. On the cultivated and non-wooded areas, analyses of ragweed would seem to give the more promising indications of zinc surface outcrops.

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BIBLIOGRAPHY.

1. Beath, O. A., 1937: The occurrence of selenium and selenium vegetation in Wyoming, Bull. 221, University of Wyoming, Agricultural Experiment Station, part II, pp. 29–63.
2. Brenchley, Winifred E., 1927: Inorganic Plant Poisons and Stimulants, 2nd ed., 133 pp., illus., Cambridge.

3. Byers, Horace G., Miller, John T., Williams, K. T., and Lakin, H. W., 1938: Selenium occurrence in certain soils in the United States with a discussion of related topics, Third Report, Tech. Bull. 601, U. S. Dept. Agriculture, 74 pp., illus.
4. Church, A. H., 1875: Some contributions to plant chemistry, Jour. Bot., London, Ser. (2) 4 (13 of whole; 169–172).
5. Dorn, Von Paul, 1937: Pflanzen als Anzeichen für Erzlagerstätten, Der Biologie (Munich) 6: 11–13.
6. Hilgard, E. W., 1911: Soils, 593 pp., illus., New York.
7. Holmes, R. S., 1944: The effect of liming the soil upon the availability to plants of zinc and copper, Research Report No. 23, Div. Soil and Fertilizer Investigations, Bureau Plant Industry, Soils and Agricultural Engineering, U. S. Dept. Agriculture, Beltsville, Md.
8. Holmes, R. S., 1945: Determination of total copper, zinc, cobalt and lead in soils and soil solutions, Soil Science 59: 77–84, 2 fig.
9. McHargue, J. S., and Roy, W. R., 1932: Mineral and nitrogen content of the leaves of some forest trees at different times in the growing season, Bot. Gaz. 94: 381–393.
10. McHargue, J. S., Hodgkiss, W. S., and Offutt, E. B., 1940: The boron content of some important forage crops, vegetables, fruit and nuts, Jour. Am. Soc. Agron. 32: 622–626.
11. Mellor, J. W., 1924: A comprehensive treatise on inorganic and theoretical chemistry, vol. 5, 1004 pp., illus., London and New York.
12. Němec, B., Babička, J., and Oborský, A., 1936: Über das vorkommen von Gold in den Schachtelhalmen, Bull. Inter. Acad. Sci. de Bohême, pp. 1–7.
13. Robinson, W. O., and Edgington, Glen, 1942: Boron content of hickory and some other trees, Soil Science 53: 309–312.
14. Robinson, W. O., and Edgington, Glen, 1945: Minor elements in plants and some accumulator plants, Soil Science 60: 15–28.
15. Singewald, J. T., Jr., 1928: The chrome industry in Maryland, Md. Geol. Survey 12: 158–191, illus.
16. Vogt, Thorolf, Braadlie, D., and Bergh, H., 1943: Geokjemisk og geobotanisk malmleting. IX. Bestemmelse Cu, Zn, Pb, Mn og Fe, i planter fra Rørosfeltet, Det Kongelige Norske Videnkabers Selskab. 26: no. 15, 55–58.
17. Wilstatter, Richard, and Stoll, Arthur, 1938: Investigations on Chlorophyll, translated from German by Shertz, Frank Milton, and A. R. Merz, 385 pp., illus., Lancaster, Pa.

REVIEWS

The Ajo Mining District, Arizona. By JAMES GILLULY. Pp. 112; plates 27; figs. 12. United States Geological Survey Prof. Paper 209, Government Printing Office, Washington, D. C., 1946 (1947).

The report on the Ajo mining district adds another to the series of detailed reports on mining districts of southern Arizona prepared by the U. S. Geological Survey during the past forty years. It again brings out the notable difference in the type of geological work by the Survey in northern and southern Arizona that has persisted through the years.

In northern Arizona and adjacent areas of the Colorado Plateau the purpose from the early days of Powell, Dutton, Gilbert, and others has been the broad correlation of the geological features over wide areas. In southern Arizona the detailed study of isolated mining districts with a minimum effort toward broad correlation has been the pattern.

This difference in plan, if plan it be, is easy to understand from the geological differences in the two regions and the differences in the economic urgency of the problems.

This report on Ajo, however, again emphasizes the need of a correlation with other areas, difficult though it may and probably will be. Since the close of pre-Cambrian time there have been a number of geological revolutions that have effected parts or perhaps all of southern Arizona. The major ones at the close of the Paleozoic, the close of the Jurassic, and the close of the Cretaceous, can each be recognized in certain areas but in the study of an isolated district like Ajo the difficulty of differentiating the major events becomes apparent in the question marks in every age determination of rocks earlier than Tertiary.

ROCKS OF THE AREA.

The oldest formation, the Cardigan gneiss, shows a low-grade metamorphism superimposed on high-grade metamorphism. The author regards the gneiss as chiefly of igneous origin and likely of pre-Cambrian age.

The Paleozoic is represented by sandstone, shale, andesite, and rhyolite, much altered by invasion of Chico Shunie quartz monzonite. This is referred without direct evidence to the Paleozoic (?). It may be remarked that volcanic activity in the Paleozoic is not widespread in southern Arizona. Other evidence of the presence of Paleozoic rocks in this area is presented in discussion of the Locomotive fanglomerate, but this suggests formations similar to those of the Vekol Mts. some 50 miles east. There is cumulative evidence[1] that the Paleozoic was deposited well across southern Arizona.

Chico Shunie Quartz Monzonite.—This intrusive is clearly more metamorphosed than the Cornelia quartz monzonite which, with other evidence, seems to place it independent of and earlier than the Cornelia intrusive. Unconformably on the Chico Shunie quartz monzonite is the Concentrator volcanics of andesite and rhyolite flows, tuffs, and breccias, much altered. These are assigned to Cretaceous

[1] McKee, Edwin D., Paleozoic sea ways in western Arizona, Am. Assoc. Petroleum Geologists, Vol. 31, pp. 282–292, 1947.

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(?) and may well correlated with the "earlier volcanics" elsewhere in southern Arizona.

Cornelia Quartz Monzonite.—The Cornelia quartz monzonite forms cross-cutting stocks with dioritic border phases. This rock contains the copper deposits of the new Cornelia mine.

Locomotive Fanglomerate.—Following a considerable period of erosion there was laid down on the Cornelia quartz monzonite and earlier formations a coarse fanglomerate with an estimated thickness of 6,000 to 12,000 feet. This is made up largely of material of the older formations of the area but also contains boulders of sedimentary rocks of Devonian, Mississippian, and Pennsylvanian age. The size and angularity of the boulders point to a local origin. This fanglomerate indicates a region of strong relief at the time of its formation and according to the author a period of continuing uplift. The author places this in middle Tertiary time.

Ajo Volcanics.—The fanglomerate passes upward into biotite and hornblende tuffs and breccias and finally into flows grouped as the Ajo volcanics.

Sneeds Andesite and Later Volcanics.—The Sneeds andesite is the basal member of a considerable thickness of andesite, basaltic andesite, and basalt that is assigned an age from middle Tertiary to Pliocene. The later volcanics are basaltic.

Aluvium.—The recent aluvium is of variable thickness.

STRUCTURE.

Structure in the Ajo district is of prime importance in its relation to the ore deposits as well as to the general geology.

The structures are divided into pre-Cambrian structures and later structures, mainly Tertiary.

Pre-Cambrian structures are confined to the Cardigan gneiss. It has been impossible to work out any very definite pattern in this isolated block of pre-Cambrian (?), though it has evidently undergone several structural deformations that did not effect the later rocks.

The structures in the later rocks are dominantly faults, and, as the later rocks are largely Tertiary (?), there is little record of structural events between pre-Cambrian (?) and Tertiary.

Faulting was intermittent through the Tertiary with large displacements.

Perhaps the most important fault in its economic effects is the Little Ajo Mountain fault which has tilted the block of ground containing the New Cornelia ore body southward at an angle of some 50 degrees.

In the main the movement on the later faults has been a tilting of blocks outlined by breaks and mainly dip slip movement. The author discusses the facts and theories relative to basin range structures. As in stratigraphy, one is impressed with the need of more facts than are now available. Each careful study emphasizes the importance of late faulting in the ore-deposit problems, and in this as in stratigraphy a correlation over southern Arizona is most urgently needed. The author is eminently qualified to discuss theories of Basin Range structures, and this feature of the report is recommended to those working elsewhere in the Basin Range province. The practical bearing of structure will be further mentioned under ore deposits.

PHYSIOGRAPHY.

The chapter on physiography is a condensation of an earlier paper on the subject by the author.

The Ajo region represents the reaction of a distinctly arid climate on rocks of varying resistence to such an environment.

The original differences in bedrock elevations were due to structural causes. Since the initiation of such differences, erosion from the higher areas and deposition in the lower areas has produced an integrated drainage, but little clastic material has been carried out of the region.

The present forms vary with the character and attitude of the component rocks. The pediments or rock floors that tend to surround the mountain blocks vary in development in general with the resistence of the type of rock to arid weathering, and the bajadas which represent the area of stream deposition slope gently away from the mountains and pediments toward the broad alluvial valleys.

Metamorphism and Ore Deposition.—Since pre-Cambrian (?) time, represented by the Cardigan gneiss, there have been several periods of structural and metamorphic changes, and the separation of the effects of each is not easy. The reviewer may call attention to the intense albitization of the Concentrator volcanics which preceded the intrusion of Cornelia quartz monzonite. The metamorphism associated with the ores accompanied and followed the intrusion of the Cornelia quartz monzonite.

The alteration associated with disseminated copper and molybdenite deposits that have been previously described may be divided into three broad over-lapping types, namely orthoclasation, sericitization and kaolinization, the latter including the several minerals of the kaolin group. The Ajo alteration comes nearest to the orthoclasation type but differs from some others in two respects, notably the high amount of albite in the altered rock and in the coarse pegmatitic character of some of the potash feldspar which occupies a north-westerly striking zone in the deposit. The latter however, is strikingly similar mineralogically and texturally to the Childs-Aldwinkle deposit [2] in the Copper Creek district, Arizona, and also to the Santo Nino deposit in the Patagonia district, Arizona.

The outstanding chemical changes in alteration are the decrease in CaO with progressive alteration, and the difference as compared with most of the disseminated deposits is the lack of removal of Na_2O. There is also more Fe_2O_3 than in most disseminated copper deposits.

The author advances the idea that the early stages of alteration, notably the replacement by orthoclase, was a late magmatic stage that took place in the apex of the stock before crystallization was complete rather than a metamorphic process after the complete crystallization of the rock. This is an idea that should encourage review of some similar deposits, especially the orthoclasation type.

The chart, "Sequence of Metamorphic Minerals," indicates that orthoclase, microcline, biotite, and magnetite had ceased to form or nearly ceased before sulphides began to deposit.

Chemically the outstanding changes were increase in silica and potassium and loss of calcium.

Weathering of the Ore Body.—An interesting feature of the weathering changes in the ore body is its separation into two distinct periods, namely: (1) Pre-Locomotive fanglomerate weathering and (2) post-locomotive fanglomerate weathering.

The pre-Locomotive weathering is expressed at the surface in a belt of chalcocite replacement in the south end of the pit adjacent to the Locomotive fanglomerate and which, from diamond drill data, is known to extend for 2,000 feet below the surface generally paralleling the tilted contact with the fanglomerate.

[2] Kuhn, Truman H., Some Arizona ore deposits, Univ. of Arizona, Ariz. Bureau of Mines Bull. 145, pp. 127–130, 1938.

In places above this chalcocite zone is a zone containing the copper as oxide, native, and carbonate, and in some places above this oxide copper zone is leached capping.

These relations are interpreted as representing weathering and enrichment which occurred previous to the deposition of the fanglomerate. The upper zones were partially or entirely removed by vigorous erosion that immediately preceded the deposit of the fanglomerate.

The post-fanglomerate alteration is of a portion of the ore body that was exposed by erosion after the tilting of the block to the south giving the earlier erosion surface and the pre-fanglomerate weathering zones a dip of 50° to 60°.

Except for the relatively narrow belt below the contact of the ore and Locomotive fanglomerate, the second period effected material that had not been altered in the pre-fanglomerate period.

In th later alteration a particularly notable feature was the very slight movement of copper.

From surface to a rather sharp plane, marked by the pre-mine water level, the sulphide minerals were very largely oxidized but there was little leaching or movement of copper.

Below this plane the primary sulphides were little changed. Some chalcocite is present but not enough to raise the tenor of the ore notably above that of the overlying oxidized zone.

The apparent striking difference in the character of alteration in pre- and post-fanglomerate time is a matter of much interest but determination of causes is hampered by the relatively limited opportunity for examination of the pre-fanglomerate alteration.

Lack of migration of copper and lack of chalcocite enrichment in the post-fanglomerate period has generally been attributed to the low content of pyrite in the deposit. The author finds that in parts of the deposit where pyrite is relatively abundant there has been chalcocite enrichment, which supports that explanation.

It is not so clear, however, that the greater migration of copper in the earlier period of oxidation was due to greater abundance of pyrite in the portion of the deposit then exposed to oxidation.

The two-stage oxidation of the Ajo ore body with a structural deformation separating them is not peculiar to the Ajo deposit but is a feature common to several ore deposits of Arizona.

The three-dimensional diagrams used to illustrate the original shape and position of the ore body and its position and shape after tilting and subsequent erosion are worthy of consideration not only by those interested in Ajo but by those interested in clear presentation of structural relations generally.

PRODUCTION AND ORE RESERVES.

The Ajo deposit is one of the earlier deposits of Arizona to be prospected and worked, however the production has been mainly since 1916. The production through 1945, except for 1935, has been:

Ore, tons, 99,887,520	Gold, ozs., 469,853
Silver, ozs., 5,320,575	Copper, pounds, 1,876,615,600
	Total Value $264,663,516.00

It may be noted that in table 8, p. 101, of the report there is an error in reporting the total ounces of gold.

There has been no recent official publication of estimates of ore reserves. A. B. Parsons in 1934, as quoted by Gilluly, estimated 200,000,000 tons of 1.1% ore. Reserves of course depend on grade of material that can be mined and the depth to which mining can be profitably extended.

The reviewer will close his remarks on this excellent report as he began them with the expression of the need for more correlation work in southern Arizona. This is not expressed as a criticism of the Ajo Report or of the work of the Geological Survey, but does express the feeling that the time has arrived for more regional work and more correlation of the geology of southern Arizona, difficult though it will be.

B. S. BUTLER.

UNIVERSITY OF ARIZONA,
June 10, 1947.

Igneous Minerals and Rocks. By ERNEST E. WAHLSTROM. Pp. 367; illust. John Wiley & Sons, New York, 1947. Price, $5.50.

This new book will attract the attention of mineralogists, petrologists and geologists because it combines microscopic determinations of rock making minerals with a classification of rocks on a new semi-quantitative basis. It is planned both for beginning students in petrography and for more advanced students who wish to classify rocks by microscopic methods.

It is in two parts. Part I, Igneous Minerals, consists of five chapters, as follows: Introduction; Optical Examination of Rock-Making Minerals; Supplementary Methods for Examining Minerals in Igneous Rocks; Minerals in Igneous Rocks; Tables for Mineral Identification. The six chapters of Part II, Igneous Rocks are: Geological Occurrence of Igneous Rocks; Structure, Texture, Color, and Alteration; Chemical Composition and Classification; Mineral Composition and Classification; Descriptions of Igneous Rocks; Microscopic Identification of Igneous Rocks; and 16 pages of index.

Under Igneous Minerals there is taken up the customary optical characteristics of minerals, physical characteristics in hand specimen, wet and dry tests, microchemical tests, staining and mineral separation. This is followed by detailed physical and optical descriptions and modes of occurrence of each mineral that enters into igneous rocks, following the customary mineral grouping. The extensive tables for identification list the mineral name, composition, and various optical and physical properties both in thin section and under immersion liquids. Other useful tables list the minerals under orthomagmatic, late magmatic or reaction minerals, pegmatitic, hydrothermal and weathering.

Under Igneous rocks the author gives modes of occurrence, physical features, alteration, textures, mode and norm calculations, classifications, and detailed descriptions of each rock family and species. The classification used by the author is, as he states, a sort of compromise using neither the rigid quantitative mineralogic classifications, nor the vague qualitative classifications. It follows Rosenbusch in a qualitative sense and Iddings and Niggli in a quantitative sense and the author regards it as semi-quantitative. He follows, however, the well known names with mineral, chemical or color modifiers rather than special names. His classification consists of 6 divisions: 1. Rocks characterized by feldspar and silica minerals, with 4 subgroups based on the ratios of alkali to soda-lime feldspars. 2. Rocks characterized by feldspar and little or no quarty or feldspathoids, with 4 subgroups based on feldspar ratios. 3. Rocks characterized by feldspars and feldspathoids (former in excess) based on feldspar ratios. 4. Rocks char-

acterized by feldspathoids and feldspars with the former in excess. 5. Rocks consisting largely of feldspathoids and/or melilite. 6. Rocks consisting largely of ferromagnesian minerals and/or ores and containing little or no feldspar or feldspathoids. The individual rocks are described under this classification.

Regardless of how the scheme of classification may be received, this book is a compilation and combination of data that will be seized upon by the beginning student as a handy and useful book for the identification of minerals in igneous rocks and for classification of rocks.

Minerals Yearbook, 1945. H. D. KEISER, Editor. Pp. 1689. U. S. Bureau of Mines, Washington, D. C., 1947. Price, $4.00.

This annual valuable compilation follows the arrangement and style of its worthy predecessors and covers the last of the war years. It fills gaps that of necessity had to be omitted in some of the preceding volumes. Under "Review of the Mineral Industries" is included government stock piling activities, the set up and activities and closing phases of the various government agencies that dealt with metals and minerals.

The customary data in production, consumption, exports, imports, prices, market conditions, new developments and future outlook, is given for each metal and mineral in the U. S. and foreign countries.

The Geology of Venezuela and Trinidad, 2nd Edit. By RALPH ALEXANDER LIDDLE. Pp. 890; pls. 90; figs. 30. Paleontological Research Institution, Ithaca, N. Y., 1946 (1947). Price, $10.00.

This fat volume follows its predecessor after 18 years and during that time new information on Venezuela and Trinidad revealed through petroleum research has been great. Intensive drilling has resulted in disclosing valuable new structural and stratigraphic data.

The first 10 chapters cover briefly the general features of the different physiographic provinces of Venezuela. The stratigraphy, metamorphic, igneous, and sedimentary rocks are treated in the next four chapters. The following 16 chapters take up the various geologic periods represented in Venezuela and the distribution of the formations. The next two chapters treat of the structural and economic geology. Trinidad is similarly covered in the last 140 pages.

The volume is a compendium of existing geological knowledge of Venezuela and Trinidad.

Review of Petroleum Geology in 1946. By F. M. VAN TUYL AND W. S. LEVINGS AND OTHERS. Pp. 316. Quart. Colo. School of Mines, Vol. 42, No. 3, Golden, Colo., 1947. Price, $2.50.

This fifth annual review has been prepared by the authors, with the collaboration of members of the faculty of the Colorado School of Mines, and other American and foreign contributors. The information contained in it is compiled from the literature, and from a canvass of geologists and geophysicists in the United States and foreign countries.

The subject matter covers advances in petroleum geology and contributory fields, progress in geophysics and geochemistry, developments in techniques, aerial photography, petroleum engineering, world exploration and development, production and reserves, and the future of the petroleum industry. Its bibliography of 3000 listings gives the volume additional value as a competent annual review.

BOOKS RECEIVED.

M. L. MIGNONE

U. S. Department of the Interior—Geological Survey.

Bull. 923. Geology and Mineral Resources of the Randolph Quadrangle, Utah-Wyoming. By G. B. RICHARDSON. Pp. 54; pls. 8; figs. 2. Washington, 1941. *Valuable reserve of phosphate rock; other mineral resources, but due to remoteness only water has been utilized.*

Bull. 952. Bibliography of North American Geology, 1944 and 1945. By EMMA MERTINS THOM. Pp. 496. Washington, 1947. *Continuation of the regular series with bibliography and index.*

Bull. 945–F. Chromite Deposits near Red Lodge, Carbon County, Montana. By H. L. JAMES. Pp. 38; figs. 7; pls. 13; tbls. 4; maps. Washington, 1946. *Cleaned chromite has 35 to 53% Cr_2O_3, but mined only 40%; reserves estimated 19,000 long tons.*

Bull. 948–A. Tungsten Deposits of Vance County, North Carolina and Mecklenburg County, Virginia. By G. H. ESPENSHADE. Pp. 17; maps, 5; fig. 1. Washington, 1947. *Huebnerite with little scheelite occur in quartz veins, cutting granite and schist; tungsten veins lie in northeast-trending belt 8 miles long by 1 mile; richer veins carry 1.0% WO_3; reserves estimated 130,000 tons indicated ore and 155,000 tons inferred ore.*

Bull. 953–A. Antimony Deposits of the Tejocotes Region, State of Oaxaca, Mexico. By DONALD E. WHITE and REINALDO GUIZA, JR. Pp. 26; figs. 2; tbls. 2; maps 9. Washington, 1947. *Richest antimony mine in Mexico; since 1942 large-scale surface mining; reserves unknown.*

Bull. 953–B. Manganese Deposits of the Republic of Haiti. By E. N. GODDARD, L. S. GARDNER and W. S. BURBANK. Pp. 25; pls. 5; figs. 2; tbl. 1. Washington, 1947. *Three main areas of deposits; mostly Cretaceous (?) volcanic rocks capped by Eocene conglomerate and limestone; origin similar to those of Cuba; estimated resources 6,000 tons ore 40% Mn and 33,750 tons of highly siliceous ore 20–25% Mn.*

Geological Survey Water Supply.

Paper 920. Utilization of Surface-Water Resources of Sevier Lake Basin, Utah. By RALF R. WOOLLEY. Pp. 393; pls. 33; figs. 21. Washington, 1947. *Storage, diversion and utility of the surface waters for future planning.*

Paper 969. Geology and Ground-Water Resources of Box Butte County, Nebraska. By R. C. CADY AND O. J. SCHERER. Pp. 102; pls. 9; figs. 4; tbls. 14. Washington, 1946. *Geologic formations of Miocene age; ground water is a moderately hard calcium and magnesium bicarbonate water chemically favorable for most uses.*

Paper 1017. Water Levels and Artesian Pressure in Observation Wells in the United States in 1944, Part 2, Southeastern States. By A. N. SAYRE AND OTHERS. Pp. 368; figs. 12. Washington, 1947. *Program of work, fluctuations of water level, well descriptions and water-level measurements in 10 different states.*

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Paper 1037. Surface Water Supply of the United States, 1945, Part 7, Lower Mississippi River Basin. By the WATER RESOURCES BRANCH. Pp. 410; fig. 1. Washington, 1947. *Measurements of stage and flow made on streams, lakes, and reservoirs in the United States.*

Paper 1038. Surface Water Supply of the United States, 1945, Part 8, Western Gulf of Mexico Basins. By the WATER RESOURCES BRANCH. Pp. 315; fig. 1. Washington, 1947. *Gaging-station records in Louisiana, Texas, New Mexico and Colorado.*

Canada Department of Mines and Resources—Mines and Geology Branch.

Map 895 A. Geological Map of Saskatchewan. 1947. *21" × 38", colored, scale 1" = 20 miles.*

Map 896 A. Mineral Map of Saskatchewan. 1947. *21" × 38", colored, scale 1" = 20 miles.*

Map 900 A. Canada Mining Areas. 1947. *27½" × 24", colored, scale ¾" = 300 miles; tables of mineral production.*

Preliminary Map 47-9. Barraute, Abitibi County, Quebec. By L. P. TREMBLAY. Ottawa, 1947. *22½" × 34", scale 2" = 1 mile. General geology and mineral occurences.*

Second Preliminary Map 47-10. Ashcroft, British Columbia. By S. DUFFELL AND K. C. MCTAGGART. Ottawa, 1947. *22" × 35", scale 1" = 2 miles, with descriptive notes.*

Cross-Index to the Maps and Illustrations of the Geological Survey and the Mines Branch of Canada, 1843–1946. By CARL FAESSLER. Geology and Mineralogy Contribution No. 75 of the Laval University, Quebec. Pp. 525. Quebec, 1946.

Geological Map Rosebud and Red Deer Sheets, No. 9 A. 1947. Combination of Maps 8 and 9 to accompany Report No. 13 by J. A. ALLAN AND J. O. G. SANDERSON. *23" × 25", scale 1" = 4 miles, colored.*

Estado de Minas Gerais—Instituto de Tecnologia Industrial.

Bol. 1. Contribuição à Genese dos Magmas Toleiticos (Contribution to the Genesis of the Tableland Magmas). By DJALMA GUIMARÃES. Belo Horizonte, 1946. Pp. 93; photos 8; pls. 7.

Bol. 2. Enstenitização e o Zoneamento dos Plagioclásios (Enstatization and Zoning of the Plagioclases). By DJALMA GUIMARÃES. Pp. 27; photos 6; pls. 4. Belo Horizonte, 1946. *Physico-chemical interpretation of the enstatization process; magmatic assimilation.*

Brasil—Conselho Nacional do Petróleo—Relatório de 1945. Pp. 218; figs. 25. Rio de Janeiro, 1947. *Objectives and Legislation; work done by the Petroleum Committee in 1945.*

Building Stones of Central Texas. By V. E. BARNES, R. F. DAWSON AND G. A. PARKINSON. University of Texas Publication No. 4246. Austin, 1942 (1947). Pp. 193; figs. 18; pls. 6; map. *Description of the building stones by groups and localities; physical tests.*

Geological Survey of Ohio.

Map of Meigs Creek Coal in Caldwell, Quadrangle, Ohio. By GEO. W. WHITE. Columbus, 1947. *13½" × 17½", colored, scale 1⅛" = 1 mile.*

Map of Meigs Creek Coal in Cumberland Quadrangle, Ohio. By GEO. W. WHITE. Columbus, 1947. *13½" × 17½", colored, scale 1⅛" = 1 mile.*

Report of Investigations No. 1. Waynesburg Coal in Harrison and Northern Belmon Counties, Ohio and Revision of Dunkard (Permian) Boundary. By GEORGE W. WHITE. Pp. 4; map in colors; plate. Columbus, 1946. *Bright, banded, bituminous coal up to 3 to 3½' thick and more extensive than formerly known.*

Report of Investigations No. 2. Geologic Section of the Chillicothe Test-Core. By J. ERNEST CARMAN. Pp. 6; fig. 1. Columbus, 1947.

Reports and Maps on the Geology and Mineral Resources of Ohio. By GEORGE W. WHITE. Pp. 16. Columbus, 1947. *List of publications since 1903.*

The Water Resources of Tuscarawas County, Ohio. By JAMES W. CUMMINS AND EARL E. SANDERSON. Ohio Water Resources Board. Pp. 51; pls. 18; tbls. 30. Columbus 1947. *Geography, geology, utilization of water, ground water and surface water, but no quantitative investigation.*

Report of the State Geologist. By EDWARD L. CLARK. Missouri Geological Survey. Pp. 43. Rolla, 1946. *Activities, finances and mineral production.*

Illinois Geological Survey.

Bull. 37. The Causes and Effects of Sedimentation in Lake Decatur. By CARL B. BROWN, J. B. STALL AND E. E. DETURK. Pp. 62; figs. 15; tbls. 7. Urbana, 1947. *Economic losses from sedimentation; remedial measures.*

Bull. 71. Use of Illinois Coal for production of Metallurgical Coke. By F. H. REED, H. W. JACKMAN, O. W. REES, G. R. YOHE AND P. W. HENLINE. Pp. 132; figs. 9; tbls. 36. Urbana, 1947. *Promising tests for metallurgical coke production.*

Geological Survey of Wyoming.

Bull. 36. Some Rocks and Soils of High Selenium Content. By O. A. BEATH, A. F. HAGNER AND C. S. GILBERT. Pp. 23; figs. 6. Laramie, 1946. *Form of selenium in different rocks, shales and soils.*

Bull. 37. Geology of Bentonite Deposits near Casper, Natrona County, Wyoming. By GABRIEL DENGO. Pp. 28; figs. 5; pls. 3; tbls. 5. Laramie, 1946. *Beds formations of Upper Cretaceous age; description of most important deposits; economic features and estimates of tonnage.*

Kansas Geological Survey.

Bull. 68. Exploration for Oil and Gas in Western Kansas during 1946. By WALTER A. VER WIEBE. Pp. 111; figs. 30; tbls. 42. Lawrence, 1947. *96,624,272 barrels of oil and 143,005,164 thousand cubic feet of gas in 1946; development by counties.*

Preliminary Cross Section No. 4. Subsurface Geologic Cross Section from Scott County, Kansas, to Otero County, Colorado. By JOHN C. MAHER. Pp. 11; columnar sections. Lawrence, 1947. *Methods of investigation; stratigraphy; structural features; oil and gas.*

Barite, Fluorite, Galena, Sphalerite Veins of Middle Tennessee. By W. B. JEWELL. Tennessee Division of Geology, Bull. 51. Pp. 114; fig. 1; pls. 12; tbls. 3. Nashville, 1947. *Rocks mostly limestones of Ordovician age; vein minerals; mining, milling and prospecting; economic considerations.*

Geology and Geography. By M. Y. WILLIAMS. Pp. 15. Ottawa, 1946. *Short history of the earth sciences; their beneficial influence on agriculture; their present tendencies.*

Quebec Division of Geological Surveys.

Rep. 24. Tonnancourt-Holmes Map-Area, Abitibi County. By W. W. LONGLEY. Pp. 21; pls. 4; colored map. Quebec, 1946. *Numerous rolls and ridges, mostly greenstone Precambrian; general east-west trend; gold contents does not seem to offer great economic possibilities.*

Rep. 31. Peat in Quebec, its Origin, Distribution and Utilization. By H. GIRARD. Pp. 48; figs. 6; pls. 19; maps 3. Quebec, 1947. *Important natural resources for agricultural and industrial purposes.*

Composition and Properties of Petroleum in West Virginia. By A. J. W. HEADLEE, R. E. MCCLELLAND AND H. A. KOSKINS. West Virginia Geological and Economic Survey Report of Investigations No. 3. Pp. 23; figs. 4. Morgantown, 1947. *Petroleum is mainly paraffin hydrocarbons with few aromatics and naphtenes; extensive tables of properties of samples.*

Pertlogy of the Columbia Falls Quadrangle, Me. By RUTH D. TERZAGHI. Maine Geological Survey Bull. 3. Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 274. Pp. 18; figs. 2; map. Augusta, 1946. *Oldest rocks possibly pre-Cambrian; Silurian volcanic and sedimentary rocks; granites; intrusives.*

Mississippi Geological Survey.

Bull. 64. Itawamba County Mineral Resources. Geology, by FRANKLIN EARL VESTAL. **Tests,** by HARRY J. KNOLLMAN. Pp. 151; figs. 16; pls. 2. University, 1947. *The mineral substances are ceramic, clays, bentonite, sand and gravel; no oil or gas in commercial quantities yet found. Laboratory tests and chemical analysis of minerals.*

Canadian Mines Handbook, 1947. Pp. 424. Northern Mines Press. Toronto, 1947. *Continuation of a well known series giving all pertinent data of principal mining companies of Canada and a supplementary list of inactive and extinct companies.*

Geology and Ground-Water Resources of Scott County, Kansas. By HERBERT A. WAITE. Kansas Geological Survey Bull. 66. Pp. 216; pls. 16; figs. 16. Lawrence, 1947. *Sedimentary exposed rocks from Upper Cretaceous to Recent; principal water-bearing formations are Pliocene and undifferentiated Pleistocene deposits; reservoir recharged principally by precipitation.*

SCIENTIFIC NOTES AND NEWS

FRANK C. PICKARD is mine superintendent of Tsumeb Corp., Tsumeb, South-West Africa. Formerly he was division superintendent with the Fresnillo Co., Fresnillo, Zac., Mexico.

HAROLD L. WALKER, head of the department of mining and metallurgical engineering at the University of Illinois, has been named by Governor Green as acting director of the Illinois Department of Mines and Minerals.

JOHN A. LITTLE has resigned as manager of the Normetal mine to join the Hollinger Exploration Co., where he will be in charge of development of iron ore deposits in Labrador.

HUBERT O. DE BECK has recently been engaged by the research laboratory in ceramics of the University of Texas to make a comprehensive investigation of ceramic raw materials in the state both in regard to production and beneficiation methods as well as character of resources.

C. E. WEED is president and director of Amico Mining Corp., recently organized by Anaconda Copper Mining Co., Miami Copper Co., and Inspiration Consolidated Copper Co. for the purpose of exploring undeveloped lands in the Globe-Miami mining district in Gila Co., Ariz.

WALTER N. WHITE, district engineer in charge of ground-water investigations for the U. S. Geological Survey in Texas, has retired after a period of 36 years in investigations related to water and its utilization in many parts of the country, notably in Utah, California, and New Mexico, and has been in charge of the work in Texas in cooperation with the State Board of Water Engineers since 1929. To succeed Mr. White the Geological Survey has appointed William L. Broadhurst, with the title of district geologist.

RICHARD J. ANDERSON, formerly with Alcoa Mining Co., Portland, Oreg., is managing engineer of the newly incorporated Raw Materials Survey at Portland, which was formed to collect basic factual engineering and economic data on sources of supply of raw materials needed by industry in Oregon and southern Washington.

ALEX M. MCDONALD is geologist in charge of western exploration with the Anaconda Copper Mining Co., Salt Lake City.

SHAILER S. PHILBRICK, senior geologist with the U. S. Engineers at Pittsburgh, was recently elected president of the Pittsburgh Geological Society.

DAVID B. DILL, after six years as engineer and geologist with the Cie. Aramayo de Mines en Bolivie, La Paz, has returned to this country and has joined the staff of the American Metal Co. as geologist.

EMILIO C. FRIGERIO is now geologist with Cie. Aramayo de Mines en Bolivie, La Paz, Bolivia.

JOHN B. KNABEL is in South America for Anaconda Copper Mining Co. and is in charge of exploration work in British Guiana and Brazil. He resigned from the U. S. Smelting Refining and Mining Co. some time ago.

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GEORGE C. SELFRIDGE, who was in the department of geology at the University of Utah, Salt Lake City, is geologist for the Atomic Energy Commission, New York City.

FORBES WILSON, after more than four years with the Nicaro Nickel Co. in Cuba, has returned to the States and is employed by the Freeport Sulphur Co., New York City, as assistant director of exploration.

W. J. NICHOLS, who was a professor in the department of mining engineering of the University of Toronto, has gone to England where he will be associated with Bedaux Ltd. and Four Africa Ltd.

ROBERT R. REYNOLDS is now a geologist with the newly formed Calumet Corp., Platteville, Wis., which is conducting an extensive exploration campaign for zinc ore in southwestern Wisconsin.

GEORGE R. MANSFIELD, retired geologist of the U. S. Geological Survey and until 1943 head of the section on areal and nonmetalliferous geology, died on July 11.

ARTHUR C. BEVAN, State Geologist of Virginia, Charlottesville, will transfer on September 15 to the Illinois Geological Survey, Urbana, as Principal Geologist in charge of the Geological Resources Section, succeeding Dr. Ralph E. Grim who has requested relief from administrative duties to devote more time to the Survey's research program on clay minerals. Dr. Bevan will retain his Chairmanship of the Division of Geology and Geography of the National Research Council.

WINTHROP PERRIN HAYNES, geologist for the Standard Oil Company (New Jersey), has been appointed Visiting Lecturer on Geology for the academic year 1947–1948, Harvard University officials announced yesterday. Dr. Haynes will give courses in Petroleum Geology.